U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

DOT HS 807 109
Final Report

March 1987

Heavy Truck Safety Study
Prepared in Response to:
Section 216: P.L. 98-554
October 30,1984
Motor Carrier Safety Act of 1984

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 807 109		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code / 8. Performing Organization Report No.
Heavy Truck Safety Study	5. Report Date: March, 1987 6. Performing Organization Code: 8. Performing Organization Report No.:
7. Author(s) Clarke, R. M., Leasure, Jr., W. A., Radlinski, R. W., and Smith M.	
9. Performing Organization Name and Address National Highway Traffic Safety Administration Research and Development	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 400 Seventh Street, S.W. Washington, D. C. 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code NHTSA

15. Supplementary Notes
This report was prepared by the Department of Transportation's National Highway Traffic Safety Administration in response to Section 216 of the Motor Carrier Safety Act of 1984 (P. L. 98-559; October, 1984)

16. Abstract Each year approximately 400,000 medium and heavy trucks are involved in accidents. Approximately 5500 people are killed and 175,000 injured as a result of these accidents. There are many interrelated factors which contribute to the cause of truck accidents and their consequences. This report:

- o Identifies the key vehicle related factors contributing to the cause of truck accidents (braking and handling/stability) and to the resulting fatalities and injuries (crashworthiness, notably truck aggressivity in collisions with other vehicles). It also identifies the programs and needs of enforcement agencies responsible for assuring compliance with traffic laws by commercial motor vehicle drivers;
- o Summarizes what is known about each of these issues;
- o Describes actions that can be taken now in some of the areas to make near-term improvements, and;
- o Presents research agendas for acquiring information to develop solutions to the longer-term issues in the remaining areas.

This study was carried out with the help and cooperation of truck manufacturers, employee representatives, truck operators and other parties interested in truck safety.

17. Key Words	18. Distribution Statement
Heavy Trucks, Air Brakes, Handling and Stability Rollover, Aggressivity, Traffic Law Compliance	Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
NONE	NONE		

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the help of the numerous individuals and organizations who contributed to preparing this report. The authors especially wish to acknowledge:

Guy Divita
Automated Sciences Group Inc.

for his outstanding work in developing most of the accident data that is presented in this report.

In addition, the authors wish to acknowledge the efforts of:

Frederico Montenegro
Automated Sciences Group Inc.,

Nagarajan Rangrajan and Asok Motayed
Sheladia Associates Inc.,

Henry Richardson
NHTSA/NCSA,

Paul Fancher, Robert Ervin, Thomas Gillespie,
Christopher Winkler, and Leonard Segel
University of Michigan Transportation Research Institute,

Hugh McGee and Sally Liff
Bellomo-McGee Inc.

Thomas Scheifflee and Joseph Kausch
Calspan Corp.

Donald F. Rudny
Triodyne Inc.

Judy Hilton and Keith Poindexter
Opportunity Systems Incorporated, and

Kay Colpitts, David Harkey and H. Douglas Robertson
Analysis Group, Inc.

Also, the authors thank the following police officials for providing truck enforcement information and data: 1st Lt. Raymond D. Cotton - Maryland State Police; Officer Fouty - Washington State Patrol; Lt. Steve Campbell - Louisiana State Police; Maj. C.M. Robinson - Virginia State Police; J.M. Barnett and Kent Milton - California Highway Patrol; Maj. Charles Hall - Florida Highway Patrol; Capt. Furiate - Ohio State Highway Patrol; Lt. Tom Clinkenbeard - Arizona Dept. of Public Safety; and, Sgt. James Luman - Illinois State Police.

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EXECUTIVE SUMMARY

Despite perceptions, medium and heavy trucks are involved in fewer accidents per mile of travel than are many other types of vehicles, including passenger cars. Notwithstanding, heavy truck accidents constitute a persistent problem, primarily because of the significant number of people other than truck occupants who are killed each year in truck-related accidents.

Medium and heavy trucks are involved in approximately 400,000 police-reported accidents each year. In 1984 (the most recent year for which complete statistics are available), 171,232 people were injured and 5,657 killed as a result of these accidents. The majority of these (118,835 of the injuries and 4,019 of the fatalities) were sustained by occupants of other vehicles involved in collisions with medium and heavy trucks. Between 1980 and 1984, the passenger car overall accident involvement rate dropped 15 percent while the combination-unit truck rate remained essentially unchanged. During this same period, the fatal accident involvement rate for combination-unit trucks decreased by 10 percent (while the rate for passenger cars decreased by 21 percent).

This report responds to a Congressional directive that heavy truck safety be studied in the context of: the driving behavior of truck drivers, specifically their adherence to traffic laws, and; heavy truck design and performance as it relates to their crash avoidance (braking and stability/control) and crashworthiness (truck aggressivity in collisions with other vehicles) capabilities.

To be responsive to this directive, this report:

* Identifies and defines the key issues associated with each of these topics,

* Summarizes what is known about each of these issues,

* Describes actions that can be taken now in some of the areas to make near-term improvements, and

* Lays out research agendas, which could be pursued if resources became available, for acquiring sufficient information to develop solutions to the longer-term issues that remain.

In terms of the driver-related issues, it goes without saying that efforts to ensure responsible and professional driving behavior among all the nation's truck drivers is central and critical to efforts to improve truck safety. Most truck drivers are competent professionals. Nevertheless, there is a growing perception that the driving behavior of many truck drivers is bad and getting worse. Objective data are not available, however, on the degree to which truck drivers are more or less of a problem than other drivers in this regard.

Motor carriers and drivers ultimately must be the ones who decide that professional driving behavior is the only acceptable way to operate heavy trucks. This can be accomplished, on the part of motor carriers, by continuous efforts to qualify, hire, and train only the best, most professional people to operate their trucks, coupled with consistent driver supervision and reasonable trip scheduling. For drivers, it involves adherence to the principles of professionalism, good judgment, common-sense, and courtesy.

Improper or inappropriate driving behavior - for example, speeding, following too close, erratic lane changing, etc. - is especially dangerous in heavy trucks since it places the vehicle close to its inherent stability and control limits. This is one more reason why it is imperative that truck drivers maintain a professional approach to their driving at all times.

In other instances drivers may use inappropriate driving techniques for lack of training or knowledge. Help is available to assist individual motor carriers in their driver training efforts through guides and training aids published by motor carrier representative organizations, the Professional Truck Drivers Institute of America, and industry/government sponsored films designed to help drivers better understand the braking and stability limits of their vehicles.

State governments also have an important role to play in this part of the effort to improve truck safety. At the state level, better information and data relative to truck accidents, traffic law enforcement activities, and traffic violation patterns would be helpful. Vehicle and driver inspection programs as well as motor carrier safety auditing programs will materially aid overall efforts to improve truck safety. Also, the enforcement techniques that have proven successful in one or more states need to be communicated to others and adopted.

Additionally, the provisions of the recently enacted Commercial Motor Vehicle Safety Act of 1986 ultimately should ensure that irresponsible drivers cannot hold multiple licenses. It should also ensure that all drivers will have to demonstrate their ability to safely operate the vehicle for which they are licensed.

Among the many causes of truck accidents, vehicle-related topics play a critical, if somewhat unrecognized and underreported role. In many cases, these factors, if they do not directly cause an accident to occur, make it more difficult - or in some cases, impossible - for a driver to recover from an error or avoid an unforeseen conflict. Once a crash occurs, the way trucks are designed can affect the severity of the trauma sustained by the occupants of all the vehicles involved.

In terms of the vehicle-related issues, this report highlights the fact that efforts to prevent truck accidents could be substantially aided by working to upgrade the performance of truck brake systems as well as truck handling and stability properties - especially as it relates to their tendency to roll over. An opportunity also exists - by working on the designs of the front ends of trucks - to reduce the number of fatalities among occupants of other vehicles killed in collisions with heavy trucks.

Among all vehicle-related topics (both those related to crash avoidance and crashworthiness safety improvements), efforts to improve truck brake systems should receive the highest priority. Based on available literature, the extensive data base developed through agency full-scale vehicle tests, and accident data analyses done for this report, it is estimated that brake system performance could be involved as a contributing factor in as many as one third of all truck accidents.

Efforts to improve truck brakes are complicated, however. This is due primarily to the fact that - in the case of combination unit trucks - the design and performance of more than one vehicle is involved (i.e., tractors and trailers need to have compatible performance) and the desire to achieve optimum limit performance capability (i.e., maximum stopping capability, in accident avoidance stops) must be balanced against the need for acceptable performance under much more prevalent sublimit, routine stopping conditions.

Private sector involvement is needed to solve many of these problems. Truck and trailer manufacturers can help by allocating more of their research and product development resources to addressing the design and performance issues raised in this and numerous other reports. Technical differences need to be reconciled and decisions made relative to acceptable performance limits, especially as they relate to the braking compatibility issue. More durable products whose performance is predictable over their lifespan are needed. These are subjects which can only be addressed by product designers and manufacturers since new product development is involved. This is clearly a private sector responsibility.

In this regard, it is encouraging that truck and trailer manufacturers are working together with motor carriers in the Truck Trailer Brake Research Group (TTBRG) to address some of the issues identified for the first phase of research described in the braking section of this report. The agency applauds industry efforts of this type and has provided relevant agency research to the TTBRG. For example, NHTSA has made available to the TTBRG its evaluation of brake force balance on today's trucks.

It is also encouraging to note that a domestic truck manufacturer is field testing antilock brake systems in cooperation with several motor carriers. Component suppliers in the U.S. are also actively working on new antilock designs and are planning fleet tests similar to those currently underway. The same manufacturer is evaluating antilock plans to make bobtail brake proportioning valves standard on certain models in the near future. At least two truck manufacturers have conducted extensive laboratory evaluations to better understand the performance characteristics of automatic slack adjusters to ensure that only proven systems will be utilized on their vehicles. One manufacturer is investigating the feasibility of incorporating load-sensitive brake proportioning systems on its air-suspension vehicles.

Because the truck brake issue is complicated, and because many issues remain unresolved, this report lays out a research agenda that holds promise of achieving - in the near term - compatible performance between tractors and trailers while simultaneously ensuring that brakes stay reasonably well-adjusted and that motor carriers can maintain their vehicles confident that the replacement component parts they use have equivalent performance to originally-installed parts. The report also presents plans for assessing the potential for upgraded stable stopping performance through the introduction of reliable antilock braking systems. In the longer term, it outlines an effort to increase the overall stopping performance capabilities of trucks to bring them closer to those of cars. The plans that are offered involve activities by both government and the private sector.

Efforts to improve the safety-related steering control properties of trucks would have second priority among the vehicle-related topics discussed in this report. Within this broad subject area, the primary focus would be on truck rollover tendencies. Rollovers are involved in 4-9 percent of all medium and heavy truck crashes but account for approximately one third of the single-vehicle accidents. Rollovers are involved in nearly 60 percent of all crashes fatal to truck occupants.

Many factors play a role in causing truck rollovers, not the least of which are human errors. For example, some truck drivers habitually drive their truck around curves as if it were a car, while others inadvertently attempt to negotiate unfamiliar curves at too high a speed. Cargo loading practices can also result in unbalanced or offset loads thereby decreasing a vehicle's roll stability properties.

In addition to human factors, vehicle-related properties -- primarily the high center of gravity height typical of loaded vehicles -- play a part in truck rollovers. Truck suspension characteristics also affect this tendency. These design-related properties are sometimes less than desirable in some trucks compared to others. Australian research has shown, however, that with careful attention to the selection and matching of suspension types, vehicle roll stability can be improved without sacrificing functional utility.

While trucks can never be designed to be as roll stable as cars, worst-case tendencies can be avoided through prudent vehicle specification and design. This report outlines a research and information dissemination program which hopefully will result in fewer of these less-than-optimum vehicles being specified and produced. The primary near-term outputs will be component factbooks and guides to assist truck designers and motor carriers in their trade-off analyses regarding the matching of components to optimize safety, durability, maintainability, etc., while still meeting the desired functional need for the vehicle.

The third vehicle-related subject addressed in this report, truck aggressivity, would be accorded the last priority among the vehicle-related topics only because achievable solutions are not as apparent as they are in other subject areas and because the extent to which reasonable incremental improvements can be made is not clear. Nevertheless, the issue is important since in 1984, 3423 people who were occupants of other smaller vehicles (passenger cars, pickups and vans, motorcycles, and others) were killed in two-vehicle collisions with medium and heavy trucks. In most cases, the front of the truck was involved. These 3423 fatalities represent 21 percent of the total number of all fatalities sustained by occupants of these smaller vehicles in two-vehicle collisions.

Historically, this topic has not received much attention since it was perceived to be a hopeless situation. Improvement efforts have focused instead on preventing this type of accident. This report describes an exploratory research program which could be pursued to determine if this number of fatalities could be incrementally reduced through reasonable and practical modifications to the front end designs of heavy trucks. These designs would likely result in slightly longer truck/tractor lengths. Such designs are at least conceptually feasible now that trailer length, rather than overall vehicle length, is limited for most combination-unit trucks operating on the Interstate and other designated portions of the Federal-aid primary system of highways. Future trucks designed to different size and weights constraints could possibly incorporate some aspects of this concept.

Because information is lacking on many of the vehicle-related topics discussed in this report, research plans have been developed for each of the subject areas covered. The individual project plans that are included represent the agency's best technical judgment as to how each of these topics could be pursued, given that priorities indicate that resources be allocated to that subject. There is consensus that each of these plans represents the most appropriate course of action to take if the decision is made to study that subject area further.

Collectively, working together, government and the private sector can address most of the issues discussed in this report and develop workable solutions for them. It is hoped that this report will serve as a blueprint for those efforts.

PREFACE

On behalf of the Secretary of the Department of Transportation, the National Highway Traffic Safety Administration (NHTSA) has prepared this report on heavy trucks. The report was undertaken in response to Public Law 98-554, Section 216, dated October 30, 1984. Section 216 directed the Secretary to:

> ... undertake a comprehensive study of the safety characteristics of heavy trucks, the unique problems related to heavy trucks, and the manner in which they are driven. Such study shall include an examination of the handling, braking, stability, and crash-worthiness of heavy trucks, and an examination of the programs and needs of enforcement agencies to assure compliance with traffic laws by commercial motor vehicle drivers. In carrying out such study, the Secretary shall consult with truck manufacturers, employee representatives, truck operators, and other interested parties.

The report contains a discussion of what is known about each of the issues required to be addressed, an identification of information gaps that need to be filled before further improvements can be considered, and recommended plans for obtaining the missing information.

A concerted effort has been made to prepare this and the companion Section 217 report in the full spirit of the Congressional directive that they be done in consultation with all the constituencies involved with truck safety. This was accomplished through the following method.

First, on the vehicle-related topics, NHTSA staff gathered available information and developed it into draft papers on each of the vehicle-related subjects covered in this report. The information included, in the case of braking, the extensive test work that the agency has completed at the VRTC test facility in East Liberty, Ohio, and in the case of handling and stability, the work done by the University of Michigan's Transportation Research Institute. In addition, to supplement this information, several new studies were undertaken to document the prevalence of various practices in actual on-the-road truck operations (eg. the prevalence of inoperative front wheel brakes, the distribution of truck speeds in a representative sampling of curves and exit ramps, etc.).

The draft papers explained what was known about each of the topics, outlined what information was still needed to enable reasoned decisions to be made on how to improve safety performance in each of the topic areas, and described a research agenda for obtaining that information.

Concurrent with preparing the papers, NHTSA research personnel made individual visits to the following organizations and companies, to discuss what was in the draft papers and to solicit their views as to the appropriateness and soundness of the research approaches outlined in the papers:

* Allied Automotive, Bendix Heavy Vehicle Systems Division
* American Trucking Association, Technical Advisory Group
* Ford Motor Company
* Freightliner Corporation

* General Motors Corporation
* International Brotherhood of Teamsters (IBT)
* Mack Trucks Incorporated
* Navistar International
* PACCAR Incorporated
* Rockwell International
* Volvo-White Incorporated

These visits were extremely valuable. They afforded an opportunity to discuss, in a non-adversative fashion, the pros and cons of various approaches to dealing with each of the topics under consideration. The discussions were frank and informative. They focused on the complexities and trade-offs inherent in designing, manufacturing, specifying, and operating trucks that are economical, durable, productive, and safe in the vocational application for which they are intended. These discussions greatly aided the preparation of the reports.

In addition to the visits, a public docket (Docket No, 85-17; Heavy Truck Safety Studies, 51 FR 807, January 8, 1986) was opened to solicit public views, comments, and technical data on the specific subjects required in the studies. Summaries of the comments submitted to that docket are contained in Appendix A of this report. Several of these comments contained information which was useful in preparing the report.

Finally, the Society of Automotive Engineers, with NHTSA sponsorship, held a public symposium entitled, HEAVY TRUCK SAFETY -- AN AGENDA FOR THE FUTURE, June 3-5, 1986. The purpose of the symposium was to present the draft papers for public review and discussion and, hopefully, to derive consensus as to the appropriateness of the research plans that were proposed in the papers. Over 300 people attended the symposium. Criticisms were constructive and indicated general agreement with the proposed research program plans. Modifications to the plans have been made as a result of this input.

The truck driver behavior portion of the study involved the gathering of views/perceptions and data, by means of interviews and surveys, from traffic safety enforcement agencies in the following States:

* Arizona
* California
* Florida
* Illinois
* Louisiana
* Ohio
* Virginia
* Washington

Based on the process followed, NHTSA believes that the research programs proposed in this report reflect a broad-based and informed consensus view of the best approaches to dealing with each of the issues discussed.

BACKGROUND

Efforts to improve medium and heavy truck safety are typically directed towards one of two types of activities -- the first dealing with approaches to preventing or avoiding the occurrence of accidents, the second intended to ameliorate the effects of accidents. With the exception of the discussion on truck aggressivity in truck/car collisions, this report focuses on accident prevention measures while the companion Section 217 report focuses exclusively on injury severity reduction measures. The two approaches are complementary.

This report is not intended to be a complete treatment of all the methods that can be employed to prevent truck accidents. For the most part, this report, like the companion Section 217 report, deals with vehicle-related topics. Driver-related issues are discussed, but only in the limited context of truck driving behavior issues. Many other topics (e.g., truck driver training, hazardous materials transportation, vehicle inspection programs, motor carrier safety auditing programs, etc.) are part of the overall truck safety issue. These have not been covered in this report, however, because they were beyond the scope of the Congressional directive for this study. They are, nevertheless, recognized to be important issues in the consideration of ways to improve truck safety.

Truck accidents are complex, and often lethal events. They have many interrelated causes (these are discussed in Section 1 of this report). Vehicle performance is not the principal or only reason why trucks are involved in accidents.

Notwithstanding, there is a significant and growing body of information that indicates that vehicle performance characteristics either directly cause, or at least facilitate, the occurrence of an appreciable number of medium and heavy truck accidents. Therefore, there is a continuing need, within reasonable limits, to constantly upgrade and improve truck performance characteristics. The improvement programs outlined in this report are intended to accomplish that objective, recognizing that they are not a panacea for the truck safety issue.

OBJECTIVE

The objective of this report is to identify issues involving the vehicle performance characteristics of medium and heavy trucks* which contribute to causing accidents, and to identify the capabilities of State and local law enforcement agencies to assure that commercial motor vehicle operators comply with traffic laws. An additional objective is to present an agenda for improving each of these aspects of truck safety.

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*Throughout this report, reference is made to medium and heavy trucks as being the population of vehicles for which improvements are being sought. These are single-unit and combination-unit trucks (including bobtail truck tractors) having a gross vehicle weight rating (GVWR) or (GCWR) of 10,000 lbs or greater.

SECTION 1. HEAVY TRUCK ACCIDENTS -- WHAT CAUSES THEM?

The continual search for the causes of traffic accidents traditionally has focused on whether the highway, the vehicle or the driver "caused" a given accident to occur. This single cause approach may be appropriate for the adjudication of individual accident cases (e.g., the settlement of insurance claims or the prosecution of violations of the law), but it represents a gross oversimplification of what actually happens in an overwhelming majority of traffic accidents. The real world is far more complex. Multiple variables operate simultaneously to create conditions wherein one or more factors exceed the compensatory ability or inherent performance characteristics of others.

Consider, for example, the depiction of accident likelihood as shown in Figure 1. Here it can be seen that the combined performance of a hypothetical driver and vehicle varies within some broad range of performance, which, for the purpose of this discussion, is a hypothetical metric combining variables such as driver skills and behavior, vehicle design performance and maintenance condition, etc. The demands placed on the driver and vehicle also vary depending on operating conditions, such as amount and behavior of other traffic, weather, type and locale of highway, etc.

Most of the time, driver/vehicle performance is generally greater than required for the conditions in which the vehicle is being operated. Therefore accident risk is low or moderate.

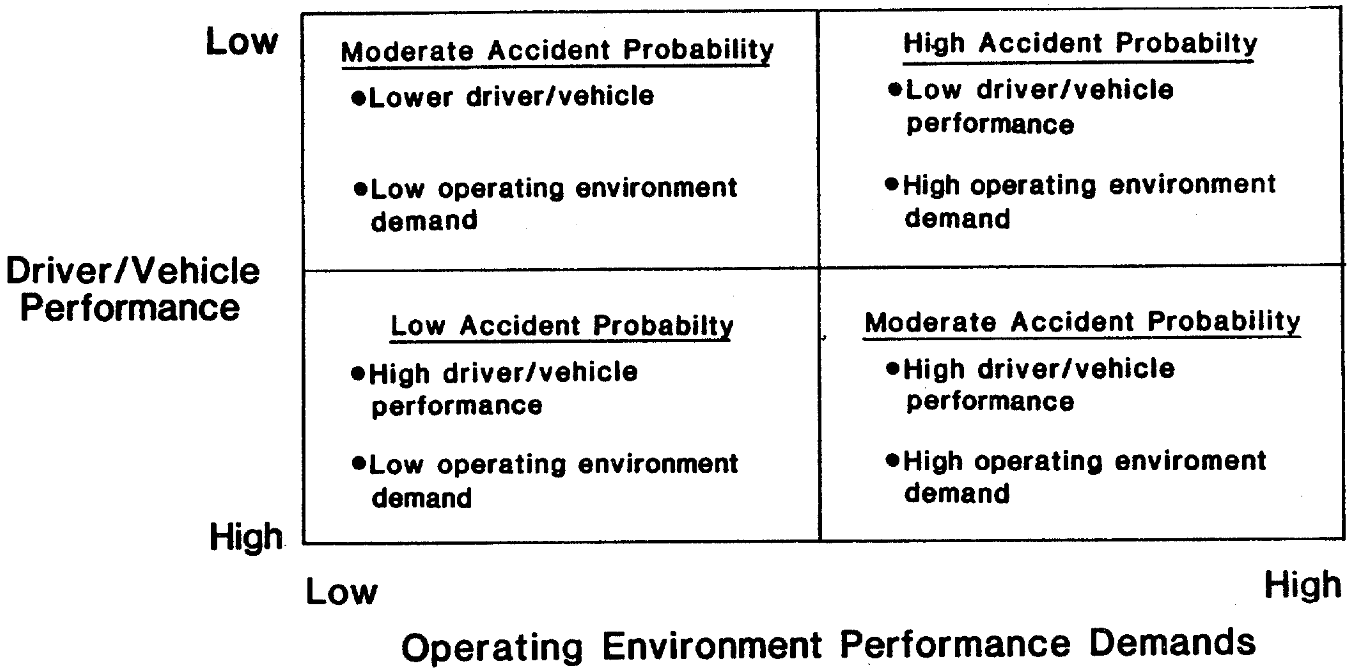
The "margin of safety" is high when vehicle/driver performance is high (i.e., the vehicle is well-maintained and equipped, the driver is well-trained and is operating the vehicle professionally), and the demands created by the operating environment are low (i.e. travel on a rural Interstate highway, with light traffic and therefore few opportunities for conflicts with other vehicles, good weather, etc.).

Accidents occur when the "margin of safety" is reduced because of changes in one or more of these variables (i.e., improper driving behavior, poor vehicle maintenance, marginal vehicle performance characteristics, bad weather, high traffic densities, two lane roads with frequent intersections, etc.) until, at some point, demands exceed performance.

Often, many of the factors which ultimately contribute to causing a particular accident may have been present for long periods of time and no accident occurs simply for lack of a "trigger" event.

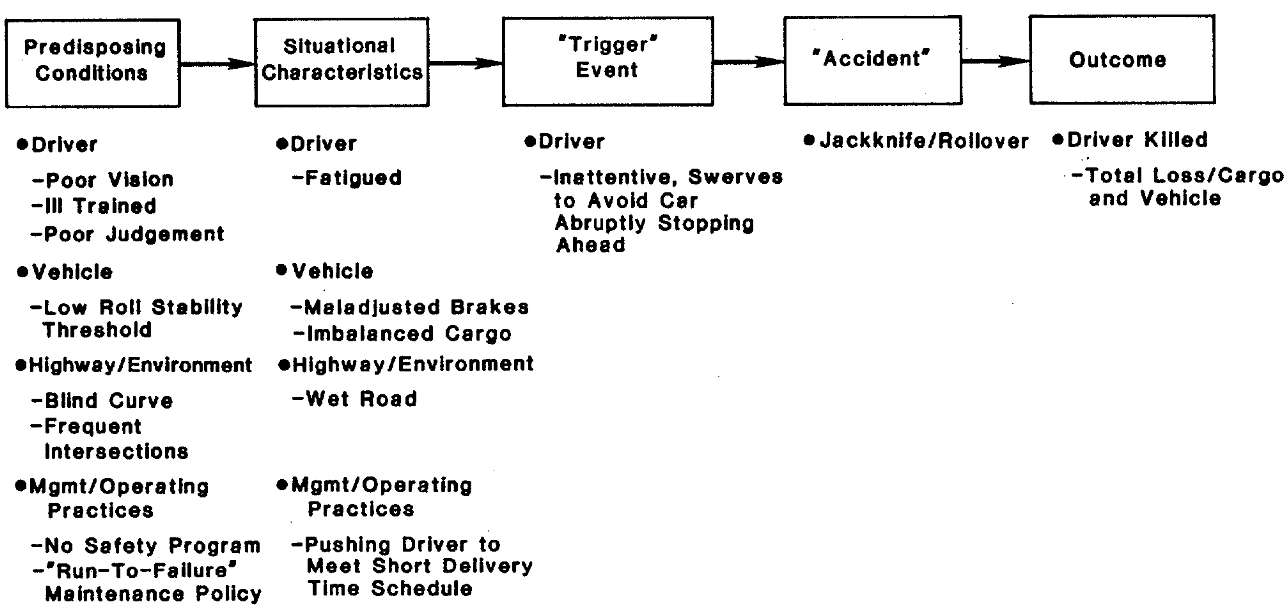
"Trigger" events are usually cited as the "cause" of most accidents. They are typically the last event in a chain of events, the one most easily established, the one that usually precipitates the actual crash. This is typically an error or misjudgment of some type on the part of a driver.

Figure 1. Accident Probability Model



Stopping at this point, however, ignores the underlying contributing role played by other factors involved; these factors either predispose, directly cause, or prevent the driver from recovering from the error (either his or some other driver's) which is typically the trigger in the accident chain. Consider, for example, the hypothetical accident described in Figure 2.

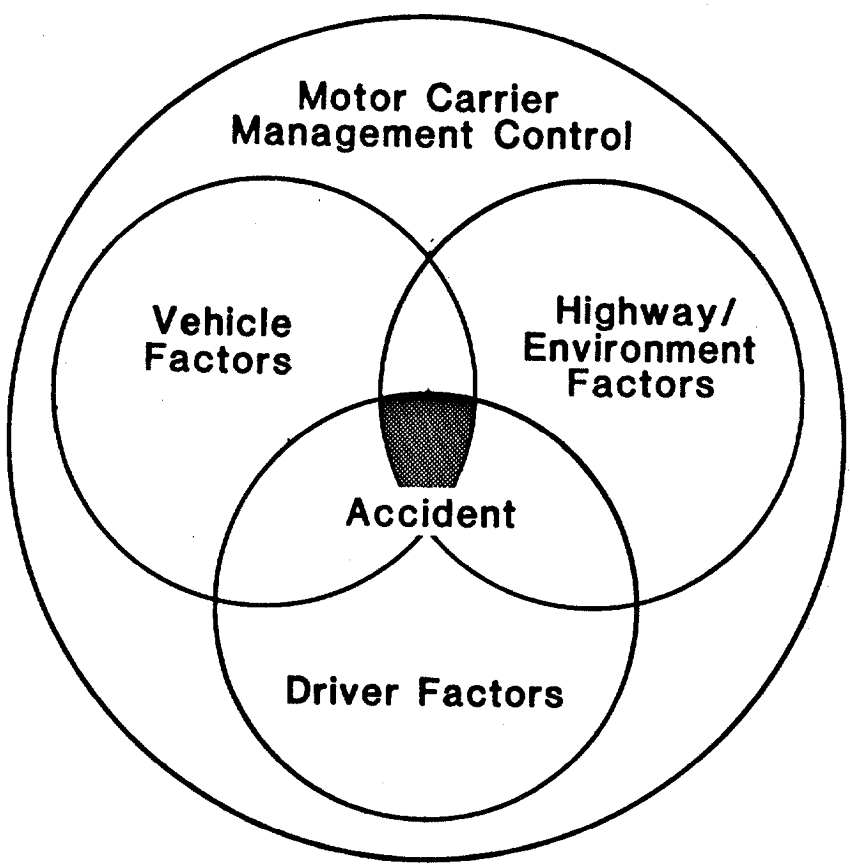
Figure 2. Heavy Truck Accident Causation "Chain"



In this case, failure to keep the vehicle under control or following too close would probably be cited as the "cause" of this accident. Many other factors were involved, however. Attempting to ascribe particular significance to one or more of them as having been the principal reason why the accident occurred oversimplifies the interrelating and often subtle influence of all the variables involved.

An alternative, and now generally accepted, way of depicting accidents is to consider the multiple factors involved as forming an interrelated causal system as shown diagrammatically in Figure 3. These factors are typically described as being related to either: drivers, vehicles, the highway environment, and in the special case of heavy trucks, motor carrier safety management and operational practices.

Figure 3. Multiple Factor Accident Causation Model



DRIVER BEHAVIOR

A great deal of attention continues to be focused on the role drivers play in causing accidents. Indeed, at least one truck driver is involved in every truck accident, making it obvious that issues related to his performance, or lack of it, are a reoccurring cause for concern.

Driver behavior/driving performance is a variable generally recognized to be affected by factors both internal and external to the driver himself. They include, but are not limited to, the following:

Internal Factors Affecting Driver Behavior/Driving Performance

* Age (As an inferential indicator of risk-taking tendencies and experience)

* Skill/Training
  - Amount, Type, Quality, And Currency of Training Received

* Physical Attributes (Permanent)
  - Visual Capabilities
  - Hearing, etc.

* Physical Condition (Temporary)
  - Fatigued
  - Temporarily sick
  - Drunk

* Psychological Condition
  - Personality/Attitude
  - Home Life Situation/Stability
  - Financial Solvency,
  - Job Satisfaction/Security

External Factors Effecting Driver Behavior/Driving Performance

* Type of Supervision Exercised
  - Consistent, Reasonable, Equitable
  - Held Accountable for Actions/Rewarded for "Good" Performance

* Institutional Controls
  - Driver Licensing
  - Driver Qualification by Employing Motor Carrier
  - Traffic Law Enforcement

Substandard or questionable aspects of any of these underlying issues could be significant contributing factors in any given accident.

VEHICLE FACTORS

Vehicle related safety issues are typically categorized as either: inherent vehicle based properties which are a function of the vehicle's design and performance characteristics; or, tendencies or conditions which result from lack of maintenance or questionable/ marginal operating practices. They include, but are not limited to, the following:

Inherent Vehicle Properties Affecting Its Safety Performance

*Brake System Capabilities
- Brake Force Balance and Timing Characteristics
- Wheel Lockup Tendencies
- Stopping Distance Performance
- Adjustment Tendencies

* Dynamic Stability Tendencies
- Roll Stability Limits
- Rearward Amplification (Multiple Unit Combinations)
- Yaw Stability Tendencies
- Low and High-Speed Off-Tracking

* Crashworthiness
- Cab Structural Integrity In Crashes
- Post-Crash, Non-Cargo Related Fires
- Aggressivity Tendencies In Collisions With Smaller Vehicles

* Truck Occupant Protection
- Restraint System Suitability
- Lethality of Interior Components In Crashes (Steering Wheels and Appurtenances/Surfaces)
- Structural Integrity of Cab Structure (especially in rollovers)

* Crash Avoidance Capabilities
- Lighting and Signalling
- Direct and Indirect Fields of View
- Driver Warning Devices/Driving Aids

* Driver Personal/Occupational Safety Concerns
- Ride Quality (Considered in the context of a stressor)
- Entry/Exit From the Vehicle (Concern is with slips/falls)
- Toxic Fumes

Maintenance or Operating Practices Which Affect a Vehicle's Safety Performance

* Vehicle Condition
- Broken/Worn out or Inoperative Components
- Reduced Performance (e.g., Marginal Stopping Distance Due to Lack of Maintenance)

* Cargo Loading
- Overweight
- Side-to-Side or Fore-Aft Imbalance
- Top Heavy

While some of these factors/issues can precipitate a crash (as in the case of a defective component which fails causing the vehicle to go out of control), the effects of most tend to be more subtle. They act to reduce the margins of the vehicle's operating performance capabilities to a point where, if an atypical steering or braking maneuver is attempted, the vehicle can not successfully respond. These latter tendencies are less likely to be a problem in the benign operating environments in which many trucks operate (e.g., open, rural interstate highways). However, many other trucks operate in more congested environments where better performance is more likely to be frequently needed. As volume-to-capacity ratios rise with increased truck and other vehicle travel on major arterials as well as lesser roadways, with essentially no new road construction, vehicle performance characteristics will become increasingly critical.

HIGHWAY/ENVIRONMENT

Highway and operating environment factors are often incidental issues in many accidents. They rarely "trigger" or directly precipitate vehicle crashes (examples of obvious exceptions include blinding storms or smoke clouds which obscure visibility). Like many of the more subtle driver and vehicle related issues, they are factors which make it more conducive for an accident to occur, or they create conditions which are unforgiving of mishaps or errors. They include, but are not limited to, the following:

<u>Highway/Environment Factors Conducive To Accident Occurrence</u>

* Roadway Design/Geometry
  - Sharp Curves/Steep Grades
  - Inadequate Sight Distances/Vision Obstructions
  - Poor Lighting/Signing

* Weather
  - Road Slipperiness
  - Vision Obscuration

* Time of Day
  - Nighttime Visibility
  - Sun Glare

* Exposure Issues
  - Nighttime Driving -- Exposure to other drunk drivers
  - Two lane road operations -- opportunity for head-on collisions, precluded on interstates

* Conflict Opportunities
  - Increases at intersections and with increasing traffic density

<u>Highway/Environment Factors Which Exacerbate Problems</u>

* Operating speeds
  - Higher speeds -- more lethal crash outcomes, error recovery more difficult

* Roadside/Off-Road Environment
  - Guardrails/barriers -- not designed to contain heavy trucks
  - Two lane/secondary roads -- lethal off-road objects readily present

One of the principal values of studying highway/environment factors is the insight they yield relative to mishap opportunities and especially crash outcomes/consequences. As an example, truck operations on rural, low traffic volume interstate highways are much less likely to afford opportunities for collisions with other motor vehicles than are operations on heavily travelled, high-speed urban expressways. This factor alone could explain why one type of truck or trucking operation has more collisions with other motor vehicles or more fatal crashes than another.

MOTOR CARRIER SAFETY MANAGEMENT/OPERATING PRACTICES

Motor carriers can have a large positive influence on truck safety because they have direct management control of their drivers, vehicles, and the highways on which they operate. This adds another dimension to truck safety improvement efforts and is a unique opportunity in the highway safety field.

The U.S. trucking industry is a diverse mix of carriers, drivers, and truck owners who operate under a broad range of safety practices and levels of management control. It includes large intercity common carriers, large and small businesses with private fleets, individual owner operators, and governments at all levels. Safety performance is affected by these differences.

The basic principles of good safety management practice are intuitively obvious and sound, and usually accepted as valid despite a general lack of published data linking the effects of these controls to differences in accident involvement rates. The type and level of safety management controls/practices exercised by carriers is influenced by factors that are both internal and external to the company. They include:

<u>Internal/Inherent Factors Impacting Motor Carrier Safety Management Practices</u>

* Management Philosophy and Company Economic Viability
    - Willingness and realization of need to establish a safety program
    - Availability of funds to run a safety program

* Vehicle Maintenance Policy
    - "Run to failure" vs. preventive maintenance
    - Pre & post trip inspection programs with follow-up

* Hiring Practices
    - Adequate driver screening/qualification
    - Employees vs. contractors influences type/level of control exercised
    - Pay scale/scheme -- Influences driver satisfaction/attitudes

* Driver Dispatching Practices
    - Adequate time to make run
    - Adequate between run off-duty time
    - Legal within hours of service constraints

* Size of the Operation
  - Larger operations tend more often to have established safety programs

* Type of Cargo/operation
  - Hazardous cargo operations dictate higher levels of safety management concern/control

External Factors Impacting Motor Carrier Safety Management Practices

* Insurance
  - Insurers can insist on good programs

* Institutional/legal
  - Size and weights constraints
  - Safety regulatory programs (governmental safety audits and vehicle inspection programs)
  - Traffic law enforcement
  - Driver licensing and control programs

The importance of encouraging good motor carrier safety management practices increases as many new and small carriers enter the industry. Efforts to inform and persuade these firms as to the efficacy and value of these practices have an obvious high priority under these circumstances.

SUMMARY

Motor carrier/heavy truck safety is affected by a complex and interrelated set of factors that include driver, vehicle, highway/environment, motor carrier management practice and institutional issues. No one simple explanation exists as to why trucks crash. There are no "quick and easy" answers to the many complex safety issues raised by medium/heavy commercial vehicles. A balanced heavy truck safety improvement program, if it is to be effective, needs to be cognizant of these relationships and must incorporate elements that simultaneously address all these issues in some reasonable fashion.

SECTION 2. WHAT DO WE KNOW ABOUT MEDIUM AND HEAVY TRUCK ACCIDENTS -- ACCIDENT DATA ANALYSES

INTRODUCTION

There is a great deal of confusion and conflicting reports about the accident experience of heavy trucks. Persistent questions include:

* Is the number of truck accidents going up, down, or staying the same?
* Is the number of truck accidents "bad" or "good" compared to themselves, other vehicle types, or something else?
* Is the proportion of truck accidents compared to all accidents "large"?
* Are fatalities resulting from truck accidents going up,down or staying the same?
* Is the proportion of truck accident related fatalities "large"?
* What do the accident data say causes truck accidents?
* What is the cause of shifts in any of these trends?

It is virtually impossible to address these and other questions related to heavy trucks, using a single data source. No one source exists that contains all the desired information. It, thus, becomes necessary to "piece together" answers from several sources. Imprecise answers can result; some, seemingly contradictory. Interpretation of results is another issue.

Reported differences in counts, percent distributions, or trend projections often arise from very basic and fundamental differences in:

* The type of accidents portrayed (e.g. ALL accidents, or FATAL accidents).
* The variables portrayed (e.g., number of VEHICLES involved in accidents, compared to number of ACCIDENTS, compared to number of FATALITIES resulting from accidents).
* The contents/scope/extent of the data base used to derive the information (e.g., the FARS file contains only FATAL accidents, the BMCS file contains only self-reported accidents by motor carriers who operate in interstate or foreign commerce, individual STATE or TURNPIKE AUTHORITY files obviously contain only accidents occurring in that state or on that turnpike).
* The definition/type of vehicles being described in the tally (e.g., ALL medium and heavy trucks, that is trucks with GVWR/GCWR > 10,000 lbs, versus just HEAVY trucks, those with GVWR/GCWR's > 26,000 lbs, versus just COMBINATION-UNIT trucks, etc.).

Thus, it is imperative that tables and graphs of truck accident data be closely scrutinized to ascertain exactly what is being portrayed. With these explanations and caveats as background, the following analyses of several sources of data are offered as a description of the medium and heavy truck accident experience. Throughout, special emphasis is placed on combination-unit trucks since they experience the majority of serious accidents among medium and heavy trucks.

OVERALL INVOLVEMENT IN ACCIDENTS

Medium and heavy trucks are involved in a relatively small proportion of the overall number of motor vehicle accidents which occur each year. On the other hand, because of their size and a number of other factors, when they do become involved in accidents, they are often severe. As a result, their proportional involvement in fatal accidents is higher.

Table 1 shows the number of medium and heavy trucks, as well as other vehicle types, involved in all accidents (i.e., property damage only, injury-producing, and fatal accidents). Only 3.8 percent of those vehicles were medium or heavy trucks. The majority of medium and heavy trucks involved in accidents were combination-unit trucks*.

* For purposes of this report, combination-unit trucks have been defined to include all truck tractor/semitrailer combinations, all truck/full trailer combinations, all multiple trailer combinations (i.e., "doubles", and "triples") and bobtail truck tractors.

Table 1. Vehicle Involvements in Accidents in 1984

Vehicle Type	Number of Vehicles Involved	Percent
Passenger Cars	7,731,244	76.5
Light Trucks/Vans	1,577,802	15.6
MEDIUM/HEAVY TRUCKS	382,736	3.8
(Combination-Unit trucks)	(219,156)	(2.2)
(Single-Unit trucks)	(163,580)	(1.6)
Motorcycles	184,378	1.8
Others**	227,847	2.3
Total	10,104,007	100.0

SOURCE: FARS 1984 and NASS 1984

** "Others" includes: Buses, limousines, utility vehicles (primarily 4x4's), snowmobiles, farm and construction equipment, campers, motorhomes etc.

Table 2 shows the number of medium and heavy trucks, as well as other vehicle types, involved in fatal accidents in 1984, (i.e., those in which a truck occupant, an occupant of another vehicle, or a pedestrian/cyclist was killed). In these accidents, 8.9 percent of the involved vehicles were medium or heavy trucks. Again, the majority were combination-unit trucks.

Table 2. Vehicle Involvements in Fatal Accidents in 1984

Vehicle Type	Number of Vehicles Involved	Percent
Passenger Cars	35,193	60.7
Light Trucks/Vans	11,050	19.1
MEDIUM/HEAVY TRUCKS	5,188	8.9
(Combination-Unit trucks)	(4,232)	(7.3)
(Single-Unit trucks)	(956)	(1.6)
Motorcycles	4,690	8.1
Others	1,837	3.2
Total	57,958	100.0

SOURCE: FARS 1984

The relative proportion of medium and heavy trucks involved in accidents which result in injuries only is lower than for most other vehicle types, while for fatal accident involvements, it is somewhat higher (motorcycles being an obvious exception). Table 3 shows the relative distribution of vehicle involvements in property damage only, injury-producing, and fatal accidents among the various vehicle types in 1984. In the case of medium and heavy trucks, injuries resulted in 30.1 percent of the involvements, while fatalities resulted in 1.4 percent of the involvements.

Table 3. Vehicle Involvements in Accidents by Accident Severity in 1984

Vehicle Type	Accident Severity (Percent of each vehicle type's involvements)			
	Fatal	Injury	Property Damage Only	(Total Number of Involvements)
Passenger Cars	0.5	41.9	57.6	(7,731,244)
Light Trucks/Vans	0.7	30.8	68.5	(1,577,802)
MEDIUM/HEAVY TRUCKS	1.4	30.1	68.5	(382,736)
(Combination-Unit trucks)	(1.9)	(31.1)	(67.0)	(219,156)
(Single-Unit trucks)	(0.6)	(28.8)	(70.6)	(163,580)
Motorcycles	2.5	79.1	18.4	(184,378)
Others	0.8	29.3	69.9	(227,847)
Total (All Vehicle Types)	0.6	40.1	59.3	(10,104,007)

SOURCES: FARS 1984 and NASS 1984

CONSEQUENCES OF THE ACCIDENTS

One way of gauging the relative importance of addressing the overall medium and heavy truck safety issue is to assess the consequences of these vehicles' accidents in terms of the total number of fatalities and injuries that result. Viewed this way, medium and heavy truck accidents result in 12.8 percent of all the fatalities and 4.8 percent of the injuries that occur in highway related accidents each year. These data are shown in Table 4 for 1984.

Another analysis that is frequently performed is a tally and comparison of the number of vehicle occupants killed or injured in the different types of vehicles. In this comparison, accident consequences to medium and heavy truck occupants are not a large portion of the total. Table 5 portrays the number of vehicle occupants injured and killed in accidents in 1984. Medium and heavy truck occupants comprised only 1.3 percent of the total number of vehicle occupants injured and 3.0 percent of those killed.

Table 4. Consequences of Medium and Heavy Truck Accidents in 1984

	Killed	Injured
Medium and Heavy Truck Occupants	1,087	42,999
Occupants of Other Vehicles Involved in Collisions with Medium and Heavy Trucks	4,019	118,835
Pedestrians/Cyclists Involved in Accidents with Medium and Heavy Trucks	551	9,398
Total	5,657	171,232
Total (all highway related accidents)	44,241	3,573,210
	12.8% of all Fatalities	4.8% of all Injuries

SOURCES: FARS 1984 and NASS 1984

Table 5. Motor Vehicle Occupant Injuries and Fatalities Occurring in Accidents in 1984

Vehicle Type	Number Injured	Percent of Total Injured	Number Killed	Percent of Total Killed
Passenger Cars	2,741,696	81.1	23,694	65.3
Light Trucks/Vans	378,919	11.2	5,788	16.0
MEDIUM/HEAVY TRUCKS	42,999	1.3	1,087	3.0
(Combination-Unit trucks)	(24,249)	(0.7)	(902)	(2.5)
(Single-Unit trucks)	(18,750)	(0.6)	(185)	(0.5)
Motorcycles	161,225	4.8	4,625	12.7
Others	56,025	1.6	1,077	3.0
Total	3,380,864	100.0	36,271	100.0

SOURCES: FARS 1984 and NASS 1984

The relative significance of this number of fatalities takes on a somewhat different perspective, however, if they are viewed in the context of occupational fatalities. By combining data from the National Safety Council, the FARS, and the U.S. Department of Labor, the relative involvement of truck drivers in occupationally related fatal accidents can be computed. These data, shown in Table 6. indicate that truck drivers sustain 9.3 percent of all work-related fatalities, yet comprise only 1.8 percent of the employed work force. Truck drivers sustain a considerably higher occupational fatality rate than the average for all industries.

TABLE 6. Occupational Fatalities -- 1984

Industry Group	Workers (x1000)	Deaths*	Deaths Per 100,000 Workers
All Industries	104,300	11,500	11
Trade	24,000	1,200	5
Manufacturing	19,000	1,100	6
Service	28,900	1,200	7
Government	15,900	1,400	9
Transportation & Public Utilities	5,500	1,500	27
Construction	5,700	2,200	39
Agriculture	3,400	1,600	46
TRUCK DRIVERS	1,876**	1,087***	58
Mining, Quarrying	1,000	600	60

SOURCES: *Accident Facts 1985, National Safety Council
**Employment and Earnings January 1985, U.S. Department of Labor
*** FARS 1984

As the data in Table 4 indicate, the largest portion of the total number of people injured and killed in medium and heavy truck accidents are occupants of other vehicles. Table 7 shows the total number of occupants of vehicles other than the medium and heavy truck occupants who were injured and killed in all multi-vehicle collision accidents. Also shown are those injured and killed in collisions with medium and heavy trucks. For all these other types of motor vehicles, 22.1 percent of the occupant fatalities and 4.7 percent of the injuries resulting from multi-vehicle collisions occur in collisions with medium and heavy trucks. The proportions (33.5 percent and 7.4 percent, respectively) are appreciably higher for light trucks and vans.

It is difficult to accurately assess the total cost consequences of medium and heavy truck accidents since accident outcomes vary widely depending on the type of cargo being transported (e.g., whether or not a hazardous materials spill is involved), the location of the accident (which dictates the degree to which traffic flow is disrupted or other property is damaged), the number of vehicles involved and extent of damage sustained, etc.

Two sources of information on the subject, one the annual BMCS accident data summary and the other an in-depth study of the costs associated with four representative accidents involving trucks carrying hazardous materials cargoes (Chess and Associates 1984), indicate that typical costs per truck accident are considerably higher than the average for all motor vehicle accidents (estimated to be $2,029 in 1980). Accidents reported to BMCS in 1984 averaged $10,965 per accident in property damage alone while the four accidents studied in-depth ranged from $41,715 to $406,885.

Table 7. Injuries and Fatalities Among Vehicle Occupants (Other than Medium/Heavy Truck Occupants) Involved In Multi-Vehicle Accidents in 1984

Vehicle in Which Injury or Fatality Occurred	Injuries -- All Multi-Vehicle Collisions	Injuries -- Collisions W/ Med-Hvy Trucks	Fatalities: All Multi-Vehicle Collisions	Fatalities: Collisions W/ Med-Hvy Trucks
Passenger Cars	2,132,855	96,866 (4.5%)	12,900	2,909 (22.6%)
Light Trucks/ Vans	252,384	18,608 (7.4%)	2,349	786 (33.5%)
Motorcycles	91,108	1,369 (1.5%)	2,569	231 (9.0%)
Others	40,249	1,992 (4.9%)	329	93 (28.3%)
Total	2,516,596	118,835 (4.7%)	18,147	4,019 (22.1%)

SOURCE: FARS 1984 and NASS 1984

Using the most conservative of these figures, the total estimated cost consequences of the 382,736 medium and heavy truck accident involvements which occurred in 1984 would be at least $ 4,196,700,000.

ACCIDENT RATES AND TRENDS

A direct comparison of the number of accident involvements of the various vehicle types does not take into account the relative exposure to accident involvement risk that each vehicle type experiences. Population size and average annual miles of travel obviously affect overall counts of accident involvements for each vehicle type. Accident rates, normalized in terms of accidents per 100 million miles of vehicle travel or accidents per 1000 registered vehicles, are typically used to account for these effects and to provide a more uniform basis of comparison.

Table 8 shows 1984 non-fatal and fatal accident involvement rates for passenger cars and the two principal types of medium and heavy trucks (combination-units and single-units). Using this basis of comparison, it can be seen that, compared to passenger cars, single-unit trucks experience fewer accident involvements on both a per vehicle and per mile of travel basis. On the other hand, combination-unit trucks, for the most part, have higher involvement rates, the exception being non-fatal accident involvements per mile of travel.

As the discussion later in Section 3 points out, a large part of the reason why combination-unit trucks are more frequently involved in fatal accidents, on both a per mile of travel and per vehicle basis, has to do with their operational use patterns.

Table 8. Vehicle Involvement Rates in Fatal and Non-Fatal Accidents in 1984

	Passenger Cars	Combination-Unit Trucks	Single-Unit Trucks
Vehicles*	127,866,000	1,259,500	4,389,700
Vehicle miles of travel* (millions)	1,254,300	76,900	54,300***
Vehicles in fatal accidents**	35,193	4,232	956
Vehicle involvements in fatal accidents per 1000 vehicles	0.3	3.4	0.2
Vehicle involvements in fatal accidents per 100 million miles of travel	2.8	5.5	1.8
Vehicles in non-fatal accidents****	7,696,051	214,924	162,624
Vehicle involvements in non-fatal accidents per 1000 vehicles	60	171	37
Vehicle involvements in non-fatal accidents per 100 million miles of travel	614	279	299

SOURCES: * FHWA Highway Statistics 1984 and derived from 1982 Truck Inventory and Use Survey (TIUS 1982)
** FARS 1984
*** Estimated based on Highway Statistics 1984 and TIUS 1982
**** NASS 1984

They travel, on average, over 5 times more miles per year than do both passenger cars and single-unit trucks, with many travelling 10 times or more as many miles. Therefore, they have many more opportunities to have accidents. Also -- given their size, the speed environments in which they typically operate, and a number of other factors -- when they are involved in an accident, it is much more likely to be fatal.

It is difficult to project nationwide accident rate trends over extended periods of time because either comparable accident data or mileage data are not available for the time periods in question. Consistent and reliable data on fatal accident involvements are available for all vehicle types for 1977-1984. Overall accident involvement data (both fatal and non-fatal) are only available for 1980-1984. Mileage data for single-unit trucks are available only for selected years, but are available for passenger cars and combination-unit trucks for 1977-1984.

Thus, it is possible to portray fatal accident involvement rate trends for passenger cars and combination-unit trucks for 1977-1984 and overall accident involvement rates for these two vehicle types for 1980-1984. These trends are shown in Figures 4 and 5 respectively.

Considering the fatal accident situation over the past 8 years, it can be seen in Figure 4 that the rate for passenger cars stayed essentially constant until 1980-81. Between 1980 and 1984 the rate dropped 21 percent. The rate rose slightly in 1984. Between 1977-1979 the combination-unit truck fatal accident involvement rate rose steeply. Over the next four years it dropped more steeply than it had risen but now, like the car rate, it appears to be tailing upwards slightly. Between 1980 and 1984 the combination-units' fatal accident involvement rate dropped 10 percent.

Overall accident involvement rate trends can be seen in Figure 5. Between 1980 and 1984 (the only time period for which data of this type are available), the passenger car overall accident involvement rate dropped 15 percent while the combination-unit truck overall accident involvement rate remained essentially unchanged.

Figure 4. Vehicle Involvement in Fatal Accidents
(Fatal accidents/100 million miles)

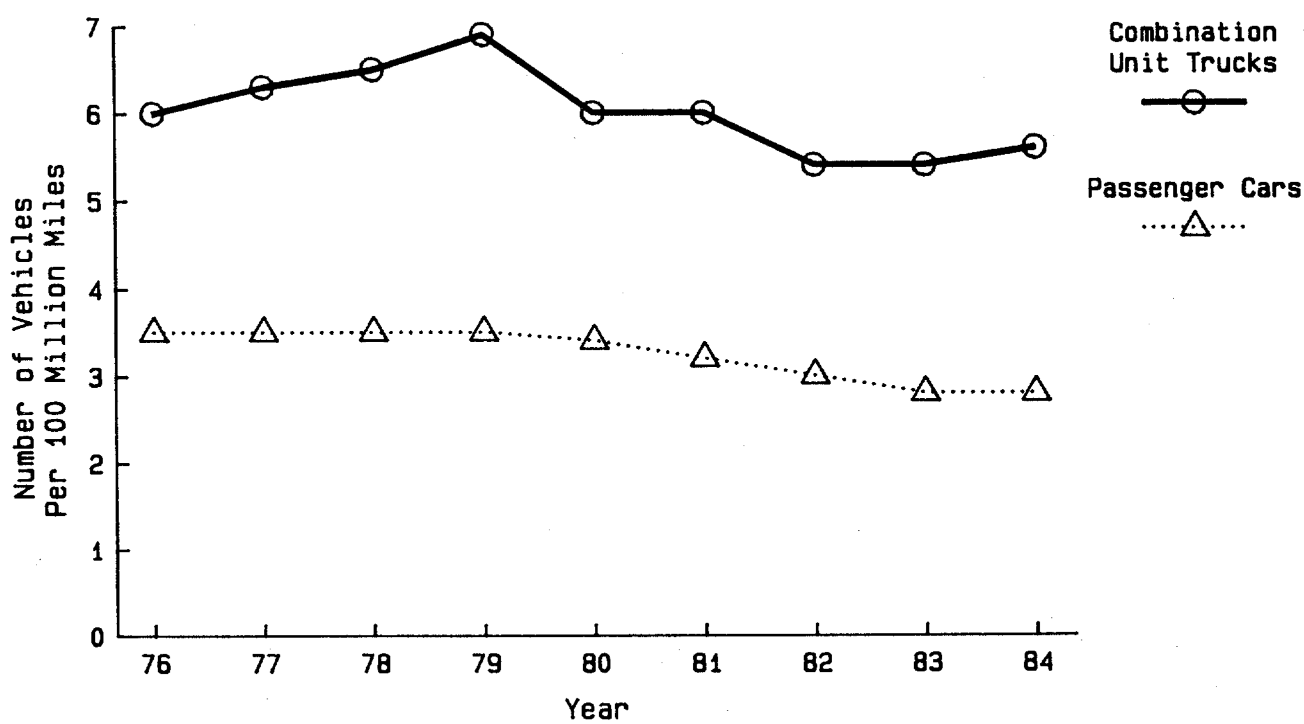
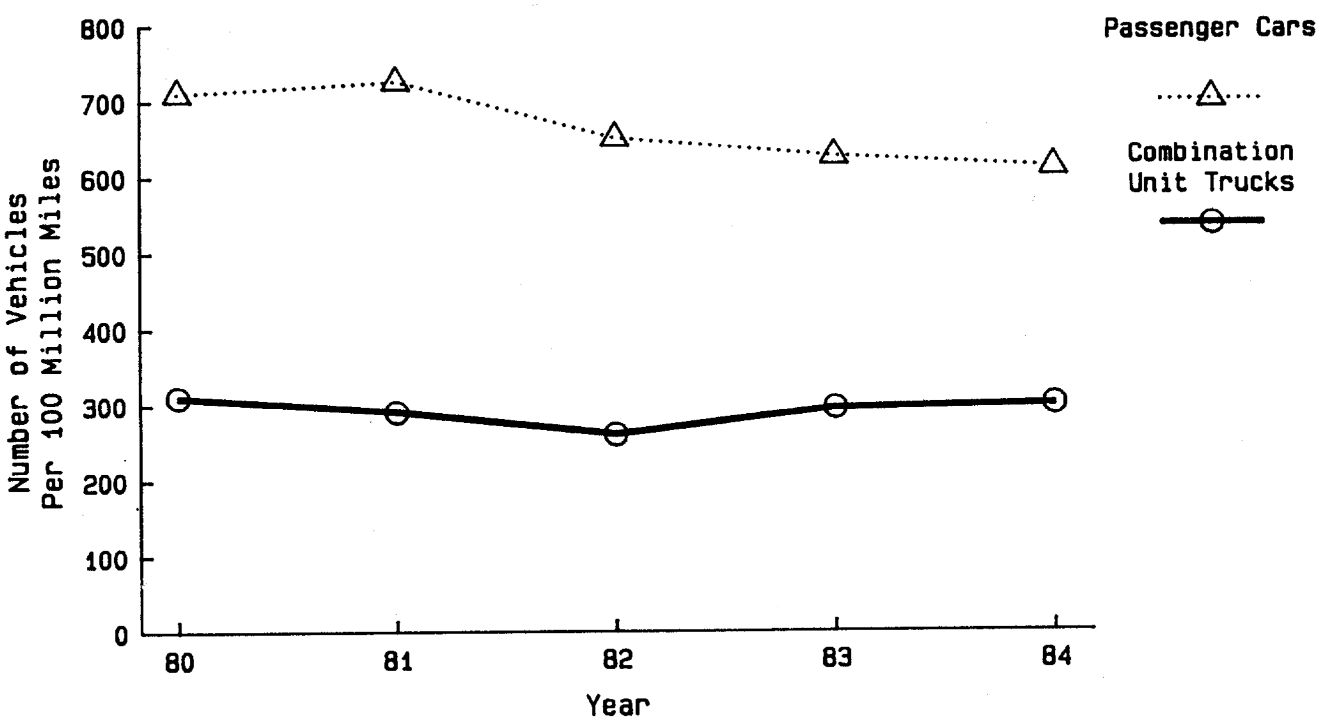


Figure 5. Vehicle Involvement Rates in Accidents
(Accidents / 100 million miles)



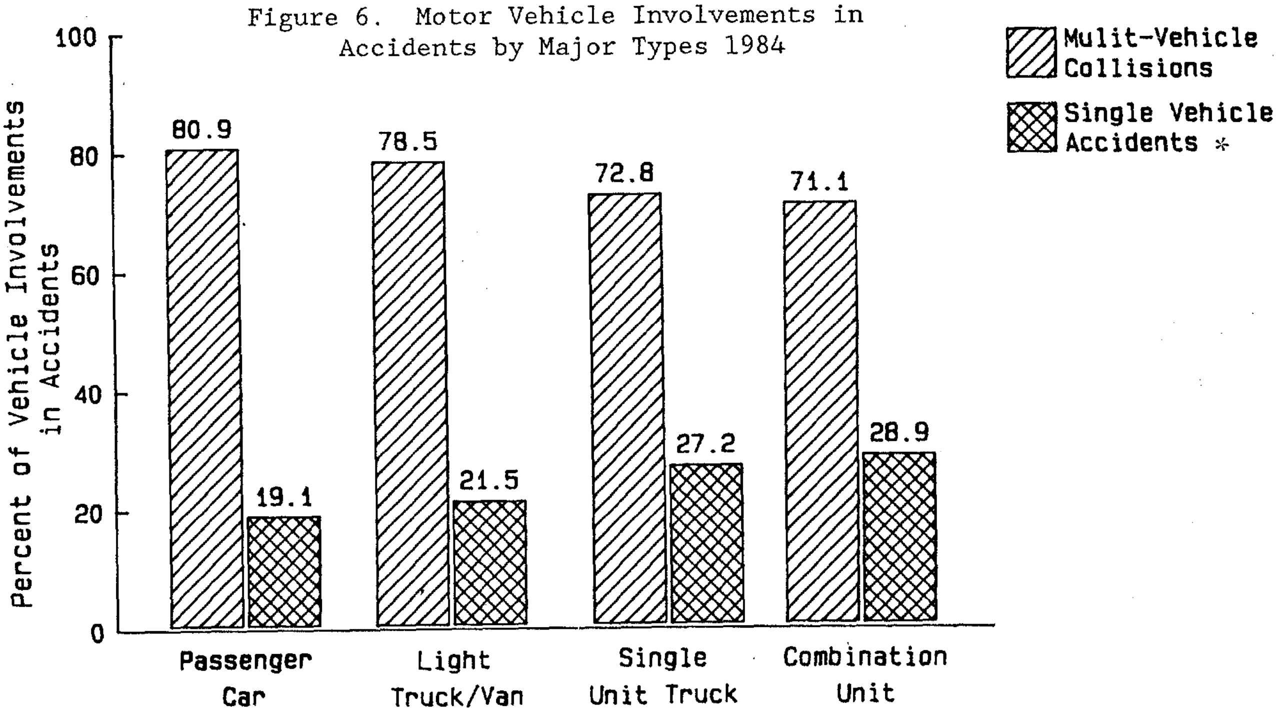
MAJOR TYPES OF ACCIDENTS

If a medium or heavy truck is involved in an accident it is most likely to be a collision with another motor vehicle. This pattern is typical for most other vehicles as well. They are, however, proportionally more involved in single-vehicle accidents (rollovers, loss-of-control/jackknifes, and collisions with roadside fixed objects) than are passenger cars and light trucks/vans (see Figure 6).

The situation is different when considering fatal accident involvements. In the case of passenger cars and light trucks/vans, there is an approximate 60/40 (multi-vehicle collisions/single-vehicle accident) ratio in terms of the types of accidents which result in fatalities, (see Figure 7). Since it is primarily the occupants of the vehicles in question (i.e., the passenger car or light truck/van) who are the accident victims, this ratio describes the comparative propensity of these two major accident types to be lethal to the vehicle's occupants.

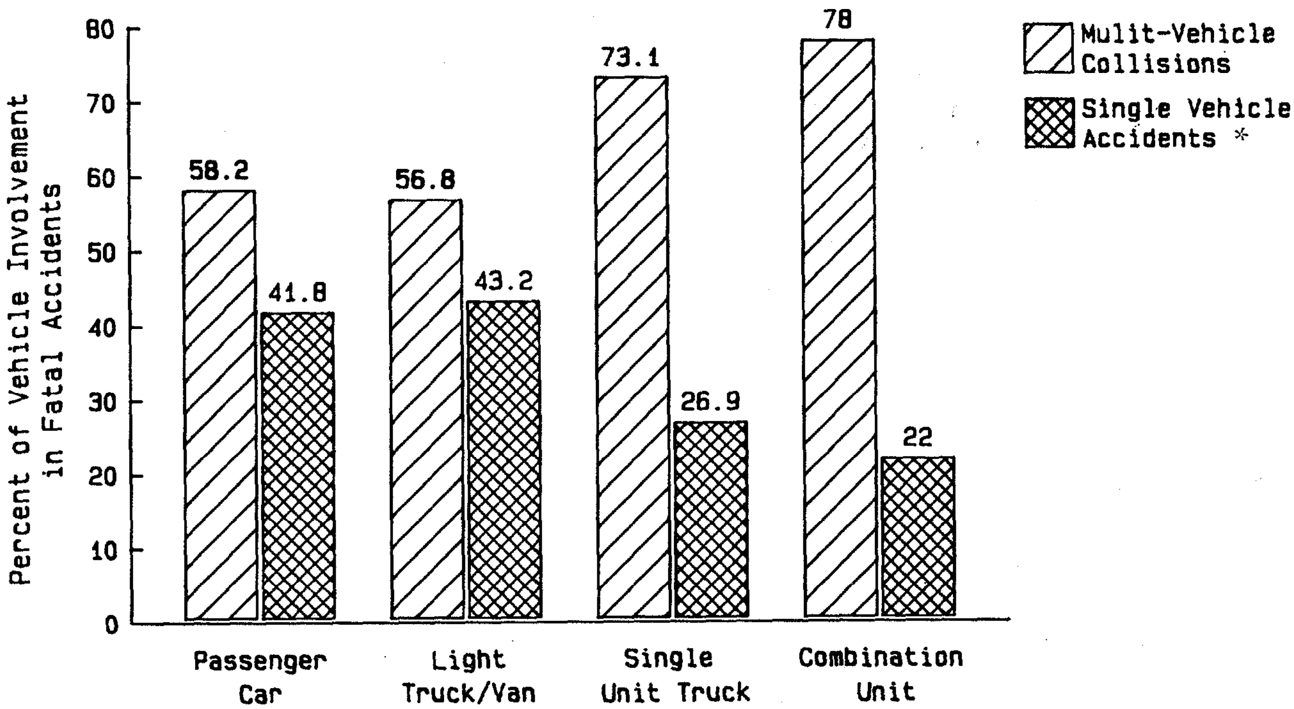
On the other hand, in the case of medium and heavy trucks, it can be seen in Figure 7 that the ratio is closer to 75/25. This is not an indication that medium and heavy truck occupants are more likely to be killed in collisions with other motor vehicles. Rather, it is an indication of the comparative lethality of collisions with other motor vehicles -- lethality to occupants of the other vehicle involved. Medium and heavy truck occupants are fatally injured primarily in single-vehicle accidents.

Figure 6. Motor Vehicle Involvements in Accidents by Major Types 1984



SOURCES: FARS 1984 and NASS 1984
* Includes: Collisions with fixed objects, loss-of-controls/ jackknifes, involvements with pedestrians/cyclists, etc.

Figure 7. Motor Vehicle Involvements in Fatal Accidents by Major Types



SOURCE: FARS 1984
* Includes: Collisions with fixed objects, loss-of-controls/ jackknifes, involvements with pedestrians/cyclists, etc..

A representative sampling of the more specific types of accidents in which single and combination-unit trucks are involved is shown in Table 9. The patterns are generally similar, but notable differences between the two types of medium and heavy trucks include comparatively:

- smaller proportional involvement of combination-unit trucks in accidents which are for the most part intersection related (i.e., angle collisions) -- most likely due to more frequent travel on limited access highways;
- larger proportional involvement of combination-unit trucks in sideswipe collisions -- most likely due to more frequent travel on road types where the truck is passing other vehicles or is being passed;
- larger proportional involvement of combination-unit trucks in collisions with fixed object and rollovers -- which is partially explained by operational differences and partially by the combination-units' rollover propensity.

Table 9. Medium and Heavy Truck Accident Types

Accident Types	Number		Percent	
	Single-units	Combination-units	Single-units	Combination-units
Collisions w/ Motor Vehicles:	6337	6242	76.1	68.1
Angle	1392	835	16.7	9.1
Head On	94	90	1.1	1.0
Rear End	1621	1286	19.5	14.0
Sideswipe	950	2018	11.4	22.0
Turning, entering/leaving road, and others	2280	2013	27.4	22.0
Single-Vehicle Accidents:	1984	2921	23.8	31.9
Collisions w/ Parked Vehicles	785	485	9.4	5.3
Collisions w/ Objects	655	1168	7.9	12.8
Rollovers	316	705	3.8	7.7
All Others	228	563	2.7	6.1
Total	8321	9163	99.9	100.0

SOURCE: Washington, 1981-1983

Finally, a more detailed breakdown of the single-vehicle, fixed object collisions (see Table 10) reveals patterns which are again most likely reflective of differences in the environments in which each vehicle is typically operated. For example, combination-unit trucks more frequently hit objects which are likely to be along Interstate or other higher speed limit facilities (i.e., guardrails, and concrete barriers), whereas single-unit trucks more frequently strike objects which are likely to be in urban, city street environments (i.e., poles and trees).

Table 10. Objects Struck by Medium and Heavy Trucks in Single-Vehicle, Fixed Object Collisions

Object Struck	Number		Percent	
	Single-units	Combination-units	Single-units	Combination-units
Posts	44	98	4.8	6.0
Poles	195	276	21.4	17.0
Guardrails	85	339	9.3	21.9
Concrete Barriers	20	92	2.5	5.7
Banks/ Ledges	48	90	5.3	5.6
Bridge Rails	23	92	3.2	5.7
Buildings	45	28	4.9	1.7
Fences	61	69	6.7	4.3
Embankments	68	79	7.5	4.9
Trees	66	37	7.2	2.3
Ditches	70	132	7.7	8.1
Underside of Bridge	28	55	3.1	3.4
All others	159	235	17.4	14.5
Total	912	1622	100.0	100.1

SOURCE: Washington, 1981-1983

DESCRIPTIVE ASPECTS OF ACCIDENTS

The search for causes of accidents very often leads to analyses of the situational (e.g., time of day, day in the week, etc.) and descriptive characteristics (e.g., roadway environment, weather conditions, etc.) associated with them. The supposition is that patterns will be apparent which will help explain why accidents occur. More often these analyses tend to confirm that accidents typically occur in situations and under conditions that reflect the way the vehicles are used rather than explaining why they crash.

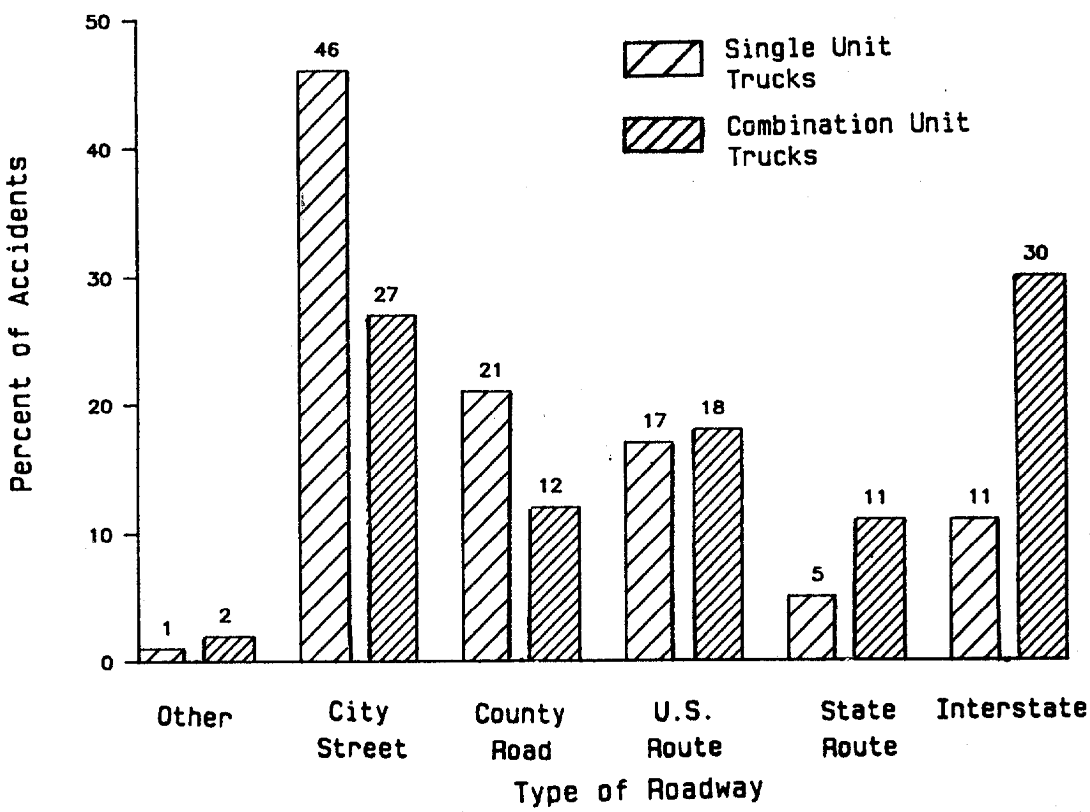
For example, medium and heavy trucks, like most other vehicles, experience most of their accidents on the roadway itself (79 percent) -- as opposed to off-road, in daylight (76 percent), on straight (79 percent), dry (66 percent), and level (69 percent) roads (Washington 1981-1983). All vehicle types have similar patterns. These proportions vary somewhat from state to state but these variations are more indicative of geographic or weather pattern differences than they are of differences in truck accident involvement propensity.

There are, however, several key descriptive characteristics of medium and heavy truck accidents (especially combination-unit truck accidents) which help explain in large part why certain accident patterns and consequences result.

A large portion of the combination-unit truck fleet is used in long distance over-the-road operations (more than 200 miles from vehicle's point of origin). Thus, it could be expected that they would accumulate a large proportion of their mileage, and therefore accident exposure risk, in rural high-speed environments, much of it on Interstates, U.S. and State Routes. Their accident patterns reflect, in varying degrees, this use pattern.

Figure 8 shows the highway types on which 17,484 single-unit and combination-unit trucks experienced accidents in Washington between 1981 and 1983. As can be seen, both truck types experienced a significant portion of their accidents on city streets and county roads. Accidents occurring in these environments result, for the most part, in low severity/no injury consequences. However, combination-unit trucks experienced a much larger proportion (59.5 percent of their total number of accidents compared to only 31.9 percent for single-unit trucks) on roadway types likely to be used in over-the-road operations (i.e., Interstates, U.S. and State routes). The speed involved with travel on these types of roads, has a direct effect on accident severity outcomes.

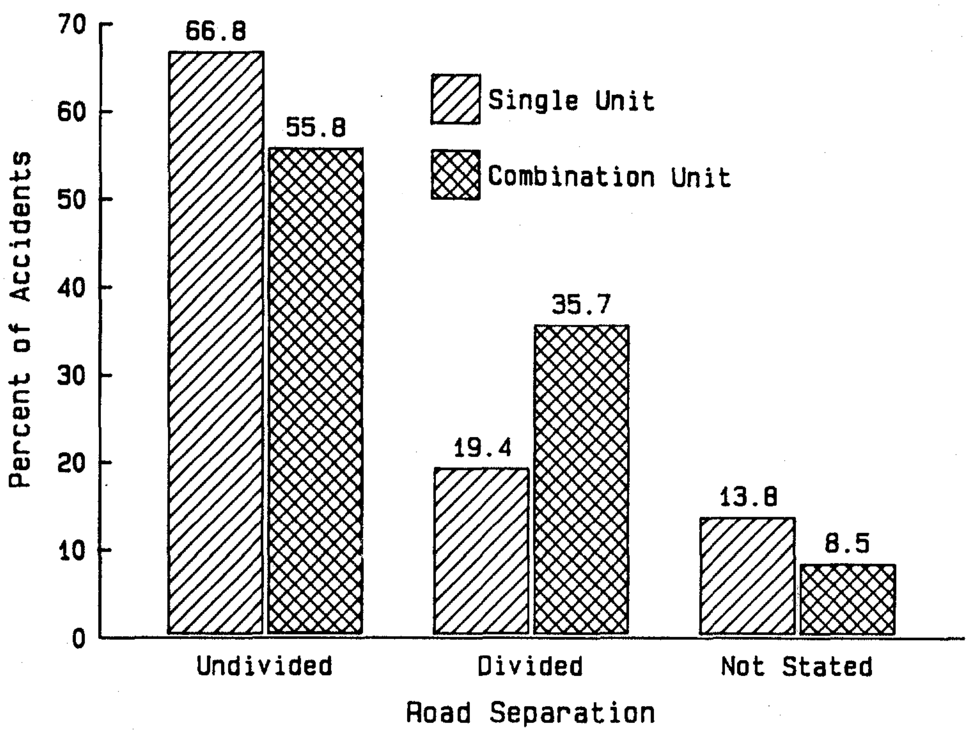
Figure 8. Medium and Heavy Truck Accidents by Highway Type



SOURCE: Washington 1981-1983

Despite the high proportion of combination-unit truck involvements on Interstates (which, for the most part, are separated/divided facilities) a large portion (55.8 percent) of combination-unit truck accidents still occur on undivided highways (see Figure 9). Travel on undivided highways provides an increased opportunity for the truck to be in conflict with other vehicles. Also, the occurrence of an accident on this type of road increases the likelihood of it being serious, since head-on collisions are possible.

Figure 9. Medium and Heavy Truck Accidents by Road Separation

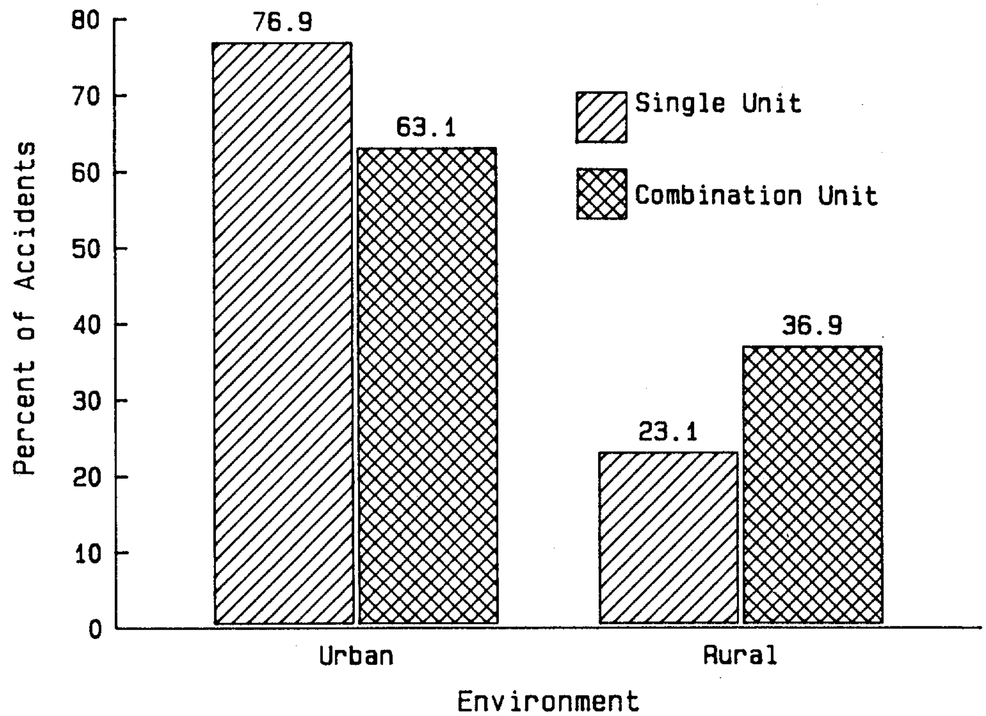


SOURCE: Washington 1981-1983

Looking at the urban/rural split (see Figure 10) the high proportion of urban (for the most part low severity outcome) accidents is still evident, but again combination-unit trucks experience significantly more rural accidents (36.9 percent) than single-unit trucks (23.1 percent) or, for that matter, passenger cars (16.8 percent in 1983).

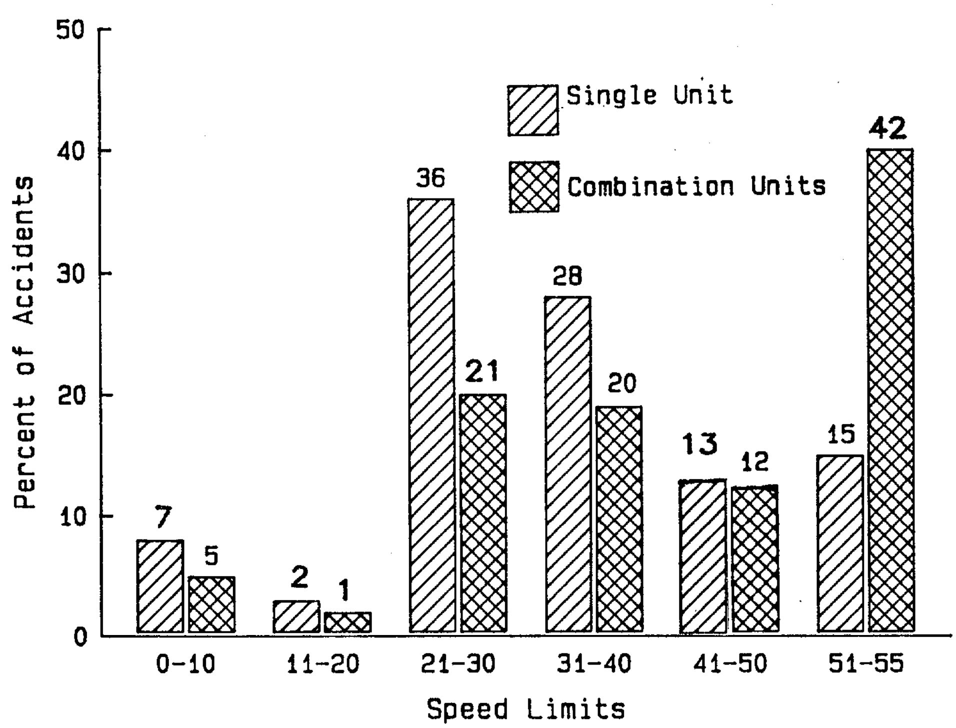
A further indication of these use pattern differences is evident in Figure 11, where it can be seen that combination-unit trucks experience the majority of their accidents (53.6 percent) on the comparatively higher speed roads (i.e., speed limits greater than 40 mph), whereas single-unit trucks experience most (71.9 percent) of their accidents on the lower speed limit roads (i.e., those 40 mph and under).

Figure 10. Medium and Heavy Truck Accidents
by Rural/Urban Environment



SOURCE: Washington 1981-1983

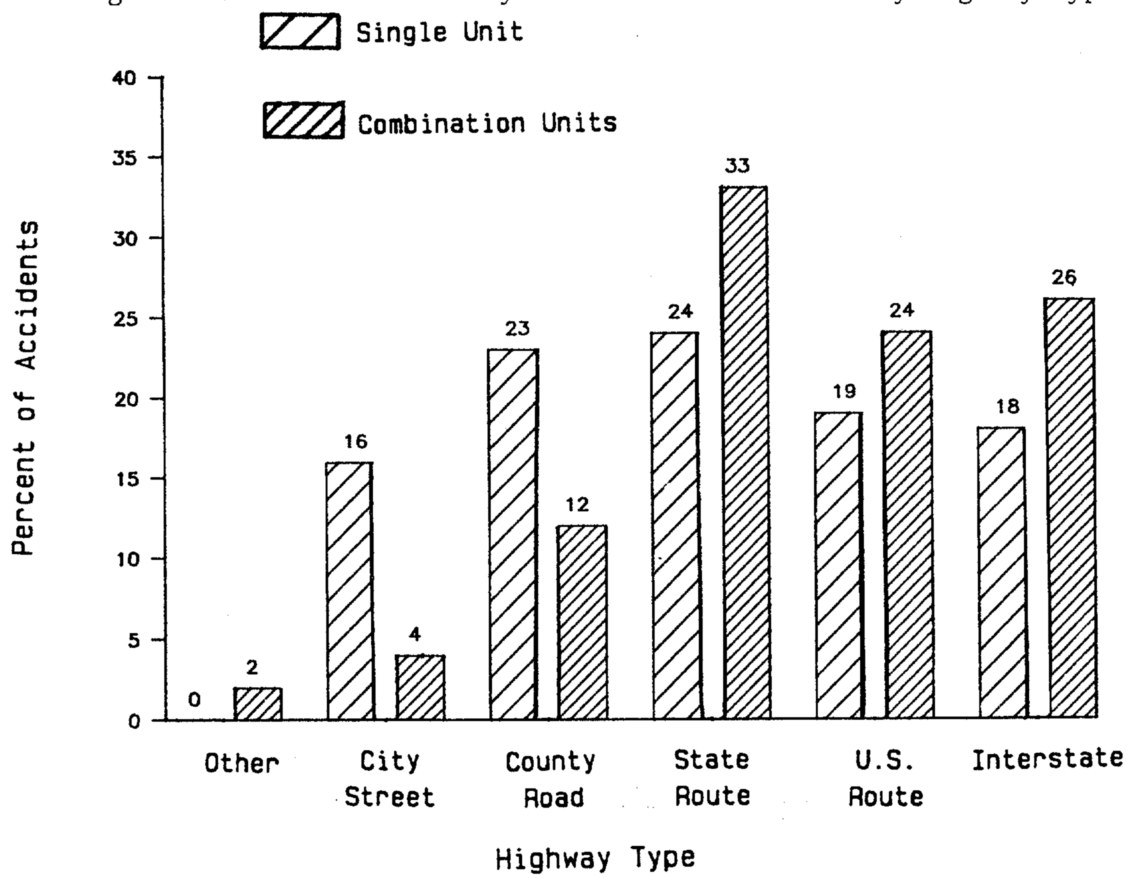
Figure 11. Medium and Heavy Truck Accidents
by Posted Speed Limits



SOURCE: Washington, 1981-1983

These differences are much more significant in fatal accident patterns. Figure 12 depicts the highway types on which medium and heavy trucks were involved in fatal accidents in Washington in 1981-1983. A comparison of these data to those shown in Figure 7 indicates that for combination-unit trucks, whereas they experience 59.5 percent of ALL their accidents on Interstates and U.S. and State routes, they experience 82. 5 percent of their FATAL accidents on these same highway types.

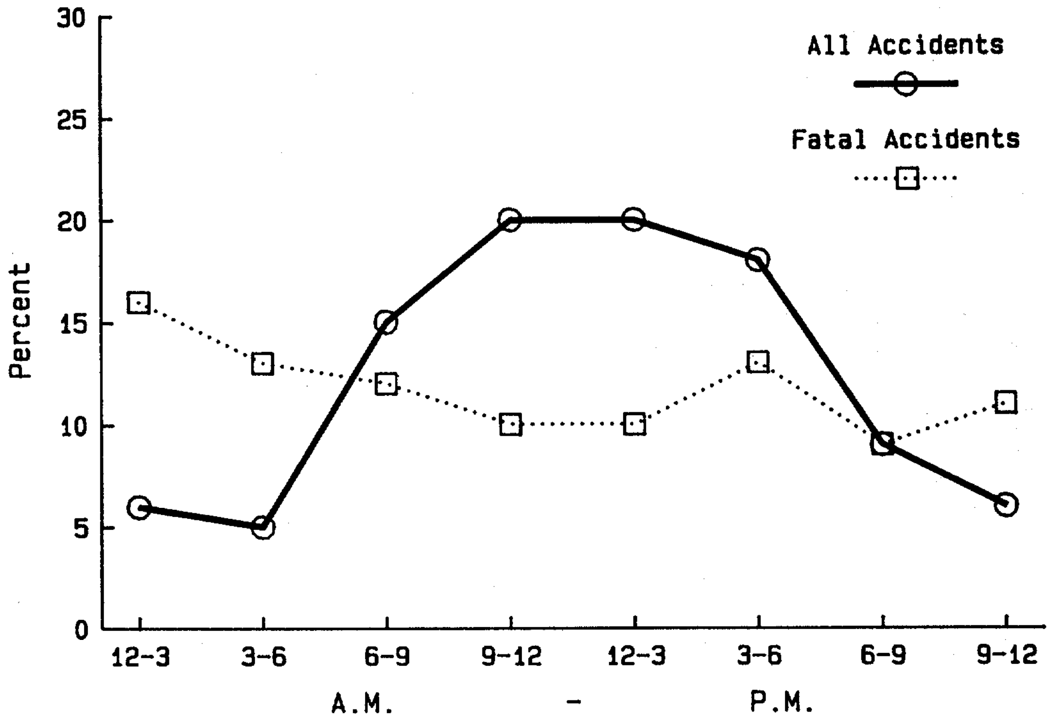
Figure 12. Medium and Heavy Truck Fatal Accidents by Highway Type



SOURCE: Washington, 1981-1983

Combination-unit truck fatal accidents occur proportionally much more at night than do "all accidents" (property-damage-only, injury and fatal accidents). This fact is reflected in the data shown in Figure 13 where it can be seen that the "all accidents" proportions peak during daylight hours (73.1 percent of "all accidents" occur between 6:00 A.M. and 6:00 P.M.) and tail off considerably during the night. However, the more serious fatal accidents occur primarily (57.9 percent) during nighttime hours (between 6:00 P.M. and 6:00 A.M.), when truck driver fatigue-related single-vehicle accidents are more likely and when high-speed truck/other vehicle collisions are possibly more prevalent.

Figure 13. All Accident and Fatal Accident Involvements by Time of Day: Combination-Unit Trucks



SOURCE: Texas, 1981-1983

Turning to FARS 1984, and considering just collisions between passenger cars and medium and heavy trucks which were fatal to the car occupant, we note that 72.5 percent of these occurred on undivided highways, 66.9 percent in rural environments, and 85.7 percent on the higher speed limit roadways. To a large degree, therefore, the lethality of passenger car/medium-heavy truck collisions seems to be explained by the opportunity for head-on encounters between the two in comparatively high-speed settings.

DRIVER AND VEHICLE FACTORS WHICH CONTRIBUTE TO CAUSING ACCIDENTS

As discussed in Section 1, there are typically numerous overlapping factors which combine to ultimately "cause" an accident to occur. Some of these are documented in accident data collection systems. Table 11 is a tabulation of the driver-related factors which were reported to have contributed to the cause of combination-unit truck accidents occurring in Washington in 1981-1983. These factors apply only to the combination-unit truck driver, not any other driver who may have also been involved in the accident. It can be seen that in 54 percent of all accidents in which combination-unit trucks were involved, the truck driver was cited for some type of error or infraction.

Table 11. Driver Related Factors Contributing to the Cause of Accidents Factors Attributed to Combination-Unit Truck Drivers

Factor	Number	Percent Total
No violation	4401	46.0
Exceeded reasonably safe speed	1227	12.8
Inattention	844	8.8
Failure to yield right of way	828	8.7
Improper turning	609	6.4
Operating defective equipment	539	5.6
Following too closely	344	3.6
Disregarded signal/stop sign/warning	154	1.6
Asleep	101	1.1
Improper passing	96	1.0
Exceeded speed limit	88	0.9
Under the influence alcohol or other drugs	67	0.7
Over centerline	64	0.7
Others	200	2.1
TOTAL	9562	100.0

SOURCE: Washington, 1981-1983

Considering collisions between combination-unit trucks and some other type of vehicle occurring in Texas during that same time period, it can be seen in Table 12 that truck drivers were cited more frequently than were other vehicle drivers.

Table 12. Driver Related Factors Contributing to the Cause of Collisions Between Combination-Unit Trucks and Another Vehicle -- Factors Attributed to Either Involved Driver

	Attributed to Combination-Unit Truck Driver		Attributed to Driver of Other Involved Vehicle	
Factor	Number	Percent	Number	Percent
Alcohol or other drugs	75	0.5	614	4.3
Speeding over limit	172	1.1	201	1.4
Speeding unsafe	1992	12.3	1146	8.0
Failed to yield	1073	6.6	1308	9.1
Disregard signal	404	2.5	285	2.0
Following too close	762	4.7	302	2.1
Improper passing	383	2.4	584	4.1
Improper turn	1355	8.3	269	1.9
Others	2395	14.7	1105	7.7
No factors	7628	47.0	8533	59.5
TOTAL	16239	100.1	14347	100.1

SOURCE: Texas, 1981-1983

While significant reductions have been made in recent years, alcohol is still involved in 43.3 percent of all fatal accidents. Alcohol is not involved proportionally in as many medium and heavy truck accidents, however, either in terms of the truck drivers or the other vehicle drivers involved. Based on a 15 state sample of fatal accidents (FARS 1984) where blood alcohol concentration (BAC) levels of fatal accident involved drivers are routinely gathered, it was found that only 2.9 percent of all truck drivers, and 16.6 percent of the other vehicle drivers had BAC's greater than 0.1. The sample found that:

* 1,101 truck drivers were involved in fatal accidents,

* Total known cases with BAC > 0.1 = 32 (2.9%)

* Total number of truck drivers killed in these accidents = 181
  - Number of truck drivers who were killed and who had known BAC > 0.1 = 24 (13.3% of those killed)

and

* 915 drivers of other vehicles were involved in a portion of these fatal accidents,

* Total known cases with BAC > 0.1 = 152 (16.6%)

* Total number of these other drivers who were killed in these accidents = 387
  - Number of these other drivers who were killed and who had known BAC .0.1 -- 144 (23.8 % of those killed)

Section 12008 of the Commercial Motor Vehicle Safety Act of 1986 calls for the National Academy of Sciences to conduct a study -- to be completed by October 27, 1987 -- of the appropriateness of reducing the blood alcohol concentration (BAC) level (from 0.10 to 0.04 percent or some other level less than 0.10 percent) at or above which a person operating a commercial vehicle would be deemed to be driving under the influence of alcohol. Based on the results of this study and the rulemaking comments, the Secretary of Transportation must promulgate a commercial driver BAC standard. If the Secretary does not issue a rule by October 27, 1988, the blood alcohol concentration level at or above which a truck driver shall be deemed to be driving under the influence of alcohol shall be 0.04 percent. States would be required to enact laws based on this standard or suffer the risk of losing federal-aid highway funds.

Turning to vehicle-related issues, one can see that while truck body type is not necessarily a direct causative factor in accidents, it is nevertheless instructive to note the relative proportion of involvements of each type in accidents (Table 13). As described in later sections of this report, the significance of these relative proportions can be better understood knowing the prevalence and use patterns of each type, as well as their comparative dynamic performance properties.

Factors related to the mechanical condition of the truck are sometimes noted as having contributed to the cause of an accident. Problems of this type are typically coded in most accident reporting systems only when equipment is obviously broken or worn out, as determined by visual inspection. Equipment that is degraded, but still intact, such as brakes

Table 13. Combination-Unit Truck Involvements in Accidents by Body Type

Body Type	Number of Involvements	Percent
Van	6,899	32.3
Platform	5,378	25.1
Tank*	4,418	20.7
Dump	2,190	10.2
Pole/Log	480	2.2
Livestock	1,369	6.4
All Others	651	3.1
Total	21,385	100.0

SOURCE: Texas 1981-1983

that are out of adjustment, is usually not reported. Table 14 indicates problems related to vehicle component parts noted on combination-unit trucks involved in accidents in Washington in 1981-1983. Brake system deficiencies are the most prevalent.

Table 14. Vehicle Related Failures/Deficiencies Contributing to the Cause of Accidents Involving Combination-Unit Trucks

Failure/Deficiency	Number	Percent
None	8,709	91.1
Broken, worn-out, inoperative brakes	314	3.3
Failures of "other" parts	243	2.5
Tires worn or smooth	94	1.0
Tires punctured or blown	62	0.7
Inoperative light system	61	0.6
Lost a wheel	43	0.5
Broken, deficient steering	24	0.3
Improper safety inspection	12	0.1
TOTAL	9,562	100.1

SOURCE: Washington 1981-1983

SUMMARY

Medium and heavy truck accidents are not particularly numerous nor are they overrepresented among all motor vehicle accidents. They are, however, unusually lethal and more often than not, it is other highway users, with whom trucks share the highways, that are the victims in these accidents. The large disparity in size and weight between trucks and other vehicles, and the typically high travel speeds (excessive or otherwise) at which they are operated, coupled with the opportunity for collisions with other vehicles, are a large part of the reason why this pattern of fatal accidents occurs. The next section of this report discusses some of these use patterns.

SECTION 3. THE U.S. TRUCKING INDUSTRY -- A DESCRIPTION OF HOW MEDIUM AND HEAVY TRUCKS ARE USED

INTRODUCTION

Many have hypothesized that heavy truck accident patterns are linked with mileage accumulation patterns. For example, it would be reasonable to expect that a fleet operating more vehicles and miles than another fleet would also be involved in more accidents, all things else being equal. Also it is reasonable to expect that how and where trucks are used strongly influences both the likelihood of their being involved in accidents and the seriousness of those accidents given their occurrence.

Data linking truck operators, the number of their vehicles, where and how much those vehicles are used, and accident patterns are not readily available. Thus, it is not possible to fully describe how truck use patterns influence truck accident patterns. Notwithstanding, the following analysis is provided as an indication of the types of information links that should be pursued to better understand the overall heavy truck safety issue.

TRUCK OPERATORS

Trucking is big business (4.0-5.5 million employees) and a vital part of the U.S. economy ($208 billion in gross revenues in 1984). Accurate counts of motor carriers and truck operators are elusive, however. Duns Marketing's TRINC file indicates there were 179,977 firms operating MVMA weight classes 6, 7, and 8 single-unit trucks and/or combination-unit trucks in 1985. The Bureau of Motor Carrier Safety's safety auditing activities have identified 217,560 truck operators engaged in interstate and foreign commerce. These are subclassified in Table 15 below:

Table 15. BMCS Motor Carriers of Record*

Carrier Type	Number	Percent Total
For-hire, common	31,265	14.4
For-hire,contract	6,604	3.0
ICC exempt	49,583	22.8
Private	121,916	56.0
Contract, U.S. Mail	3,130	1.4
Foreign	187	0.1
Migrant Worker	792	0.3
All others	4,083	1.9
Total	217,560	100.0

* As of Nov. 1985

The ICC reported there were 30,481 Class I, II, and III** for-hire common and contract carriers operating in 1984, while the Private Carriers Conference of the American Trucking Associations estimates there were between 100,000 and 125,000 private carriers operating that same year.

Based on this range of estimates, it is reasonable to assume that there are somewhere between 150,000-225,000 motor carriers operating medium and heavy trucks in the U.S. today.

SIZE OF TRUCKING OPERATIONS

Trucking operations are widely dispersed among types and sizes of operators. Although deregulation has clouded the distinctions somewhat, the traditional classifications of common/contract (for-hire) and private carriers remain one of the best ways of characterizing truck operators. Using the TRINC file as a representative indicator of the composition and distribution of combination-unit truck operators, it can be seen in Table 16, that the single largest classification of truck operators are for-hire carriers. However, these are greatly outnumbered by vocational applications which are, for the most part, private carriers.

Table 16. Motor Carrier Fleets Operating Combination-Unit Trucks by Vocational Application, 1985

Vocational Application	Number of Fleets Operating Combination-Unit Trucks	Percent of Total Fleets
For-hire	21,893	20.0
Construction	20,129	18.4
Wholesale	17,822	16.2
Manufacturing	13,055	11.9
Petroleum	7,021	6.4
Agriculture	6,821	6.2
Retail	6,659	6.1
Services	5,564	5.1
Lease/rental	4,888	4.5
Forestry/lumbering	2,248	2.0
Other	1,583	1.4
Utilities	1,035	0.9
Mining	970	0.9
Total	109,688	100.0

SOURCE: Dun's Marketing's TRINC File (MVMA Wgt. Classes 6,7,& 8 -- operators of combination-unit trucks)

** Class I motor carriers are those having annual gross operating revenues of $5 million or more. Class II operators have operating revenues of $1-5 million, while Class III carriers have less than $1 million.

Most trucking operations, both for-hire and private, are small, involving 5 trucks or less. Table 17 depicts the relative distribution of truck operations by their size.

Table 17. Motor Carrier Fleets Operating Combination-Unit Trucks by Fleet Size, 1985

Fleet Size	Type of Carrier For-Hire	Private	Total
Small (1-5)	13,585(14.9%) [65.5%]	77,634(85.1%) [87.3%]	91,219 [83.2%]
Medium (6-100)	6,615(37.5%) [31.9%]	10,998(62.5%) [12.4%]	17,613 [16.1%]
Large (101+)	543(63.4%) [2.6%]	313(36.6%) [0.3%]	856 [0.7%]
Total	20,743(18.9%)	88,945(81.1%)	109,688

SOURCE: Dun's Marketing's TRINC File

Between 1980 and 1985, major shifts occurred in the motor carrier industry. Numerous factors, such as economic deregulation, an economic recession, and changes in size and weights regulations have been cited as reasons among others for these changes. It is difficult to isolate the individual effects of any one of these changes on observed changes in the make-up of the motor carrier industry. Nevertheless, during that time period TRINC reported that the number of combination-unit truck fleets dropped in 1982-1983 but then regained numbers such that there has been an increase between 1980 and 1985 in the overall number of operators. The control of combination-unit trucks, however, has been redistributed from larger to smaller size fleets. These trends are shown in Table 18.

Table 18. Changes in Fleet Sizes Among Operators of Combination-Unit Trucks, 1980-1985

	Fleet Size 1-5	6-10	11-25	26-50	51-100	101 +	Total
No. Fleets in 1980	84,713 (85.2%)	7493 (7.5%)	4504 (4.5%)	1445 (1.5%)	674 (0.7%)	622 (0.6%)	99,451 (100%)
No. Fleets in 1985	95,151 (86.8%)	7454 (6.8%)	4413 (4.0%)	1454 (1.3%)	648 (0.6%)	568 (0.5%)	109,688 (100%)
% Change 1980-1985	+13.0%	-0.5%	-2.0%	+0.6%	-3.9%	-8.7%	+10.3%

SOURCE: Dun's Marketing's TRINC File

There is concern that small fleets may experience comparatively higher accident rates than larger fleets. For example, in a study that pre-dates some of these more recent findings, McDole and O'Day (1975) studied vehicle maintenance practices among motor carriers and found that smaller firms or individual owner operators were more likely to be associated with substandard maintenance practices than were larger fleets. Among fleets they surveyed, only 16 percent of the small fleets (20 or less vehicles in their definition) required a written pre-trip vehicle inspection, whereas 59 percent of the large fleets (21 or more vehicles) did so. They also noted that larger carriers had proportionally fewer accidents in which vehicle component part deficiencies were involved than did smaller carriers.

Campbell and Carsten (1981) also found comparatively larger fleets to be less involved in fatal accidents than smaller fleets (see Table 19).

Table 19. Fatal Accident Involvement Rates by Fleet Size: Intercity Combination-Unit Trucks Only

	Fleet Size	
	Small (1-49 vehicles)	Large (50 or more vehicles)
Fatal Accident Rate Per Hundred Million Vehicle Miles	10.4	4.6

SOURCE: Campbell and Carsten (1981)

Neither of these studies were designed to study the effects of fleet size on safety, and thus, their findings may merely reflect differences in use patterns or other factors. In addition, more recent studies related to this issue are not available. Nevertheless, the shift in control of combination-unit truck operations from larger to smaller size fleets, coupled with the Cambell and Carsten findings, highlight the need to focus attention on the safety-related needs and problems of smaller fleets.

VEHICLE DISTRIBUTION AND MILEAGE ACCUMULATION PATTERNS

There are large differences in the amount of mileage accumulated (VMT) each year by various types of medium and heavy truck operators. This mileage is accumulated in different types of operating environments as well. This is likely to influence medium and heavy truck accident patterns, if for no other reason, because it results in some fleets being exposed to the likelihood of having an accident more or less frequently than others.

There were over 38 million trucks in use in the U.S. in 1984, the majority of these being light trucks (primarily pickups) and vans. Considering just the medium and heavy truck fleet, there were 1,259,500 combination-unit and 4,389,700 medium and heavy single-unit trucks in operation. There are over three times as many single-unit trucks as there are combination-units but each combination-unit accumulates nearly 5 times the annual mileage that each single-unit truck does. This fact is one of the principal reasons why combination-unit trucks have more accidents than single-unit trucks. These data are displayed in Table 20.

Table 20. U.S. Medium and Heavy Trucks and Mileage Travelled, 1984

Truck Type	Number of Vehicles	Miles of Travel (Millions)	Average Annual Miles of Travel Per Vehicle
Single-unit	4,389,700	54,300	12,369
Combination-unit	1,259,500	76,900	61,056

SOURCE: FHWA Highway Statistics 1984, and derived from TIUS 1982

Despite the fact that small fleets outnumber medium and large fleets, they do not control the majority of combination-unit trucks nor do they accumulate most of the mileage. As can be seen in Table 21, medium sized fleets control the largest proportion of vehicles and accumulate the largest proportion of miles of travel.

Table 21. Distribution of Combination-Unit Trucks and Their Mileage by Size of Motor Carrier Operating the Vehicle

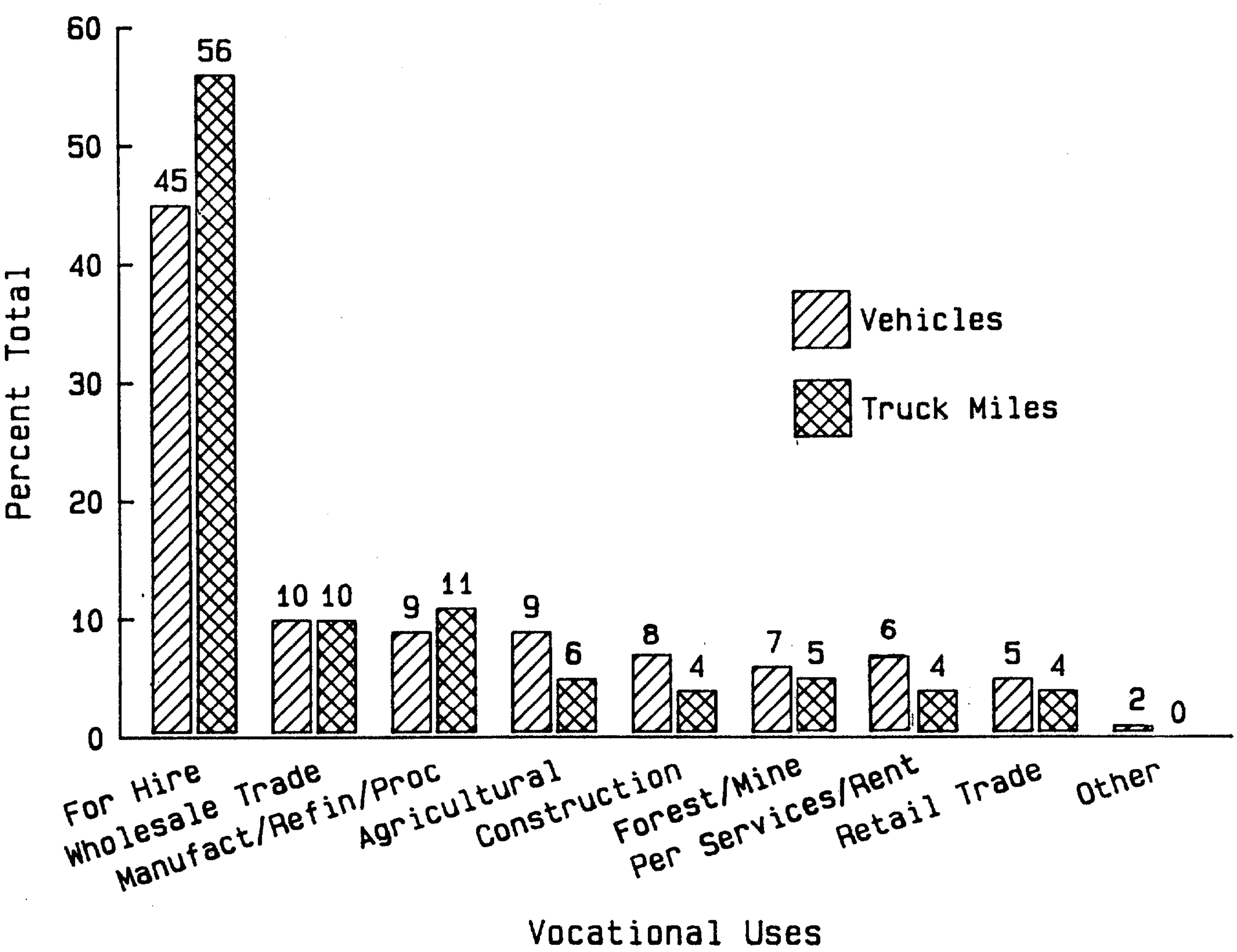
Fleet Size	Percent Total Vehicles Operated	Percent Total Mileage Accumulated
Small (1-5)	31.5	26.0
Medium (6-100)	46.9	44.7
Large (101+)	21.6	29.3

SOURCE: TIUS 1982

There are diverse types of businesses operating medium and heavy duty trucks. They include large intercity common carriers, large and small private businesses such as retailers, manufacturers, construction companies, rental and leasing firms, individual owner operators, and government at all levels. Figure 14 shows the distribution of combination-unit trucks and vehicle miles travelled by principal vocational use or function. For-hire carriers control nearly half the vehicles and accumulate slightly more than half the total mileage of combination-unit trucks. As shown in Figure 15, the majority of these for-hire carriers are large or medium sized fleets.

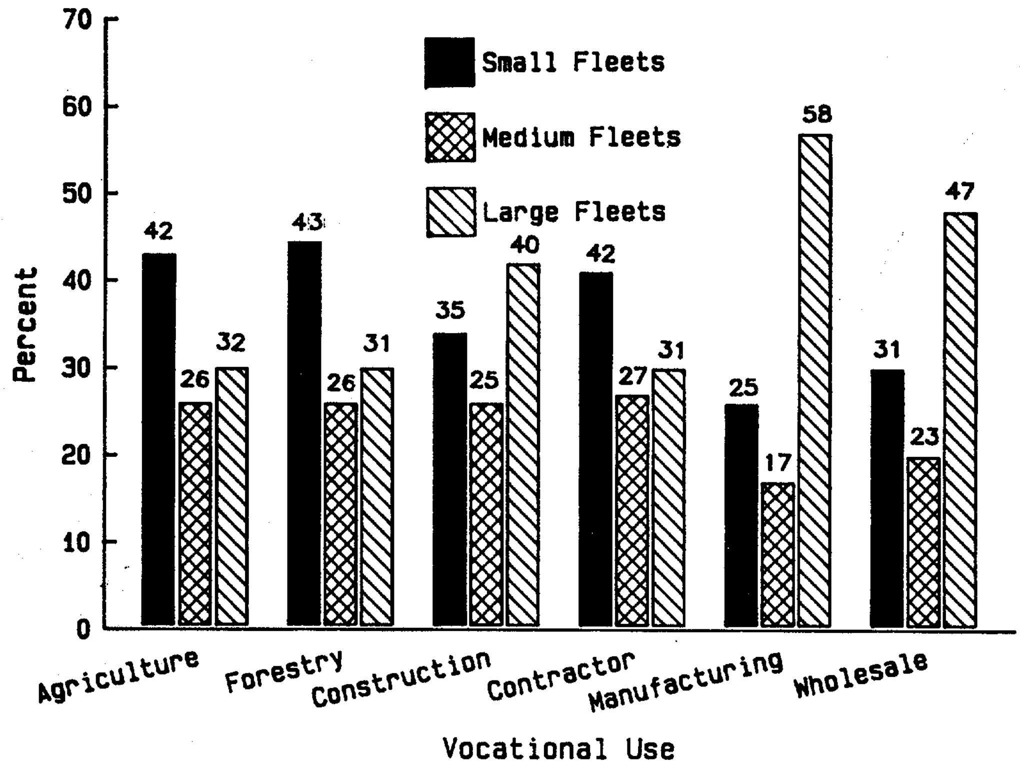
On the other hand, many other vocational uses to which combination-unit trucks are applied involve the use of smaller fleets of trucks. As indicated in Figure 15, small (1-5 vehicles) and medium sized (6-99 vehicles) fleets accumulate the majority of the combination-unit truck mileage (and, therefore, presumably the exposure to accident risk) in agriculture, wholesale, personal services, forestry, contractor activities, and "other" vocations. Large fleets (100 or more vehicles) are predominantly concentrated in for-hire, retail, rental operations, and manufacturing.

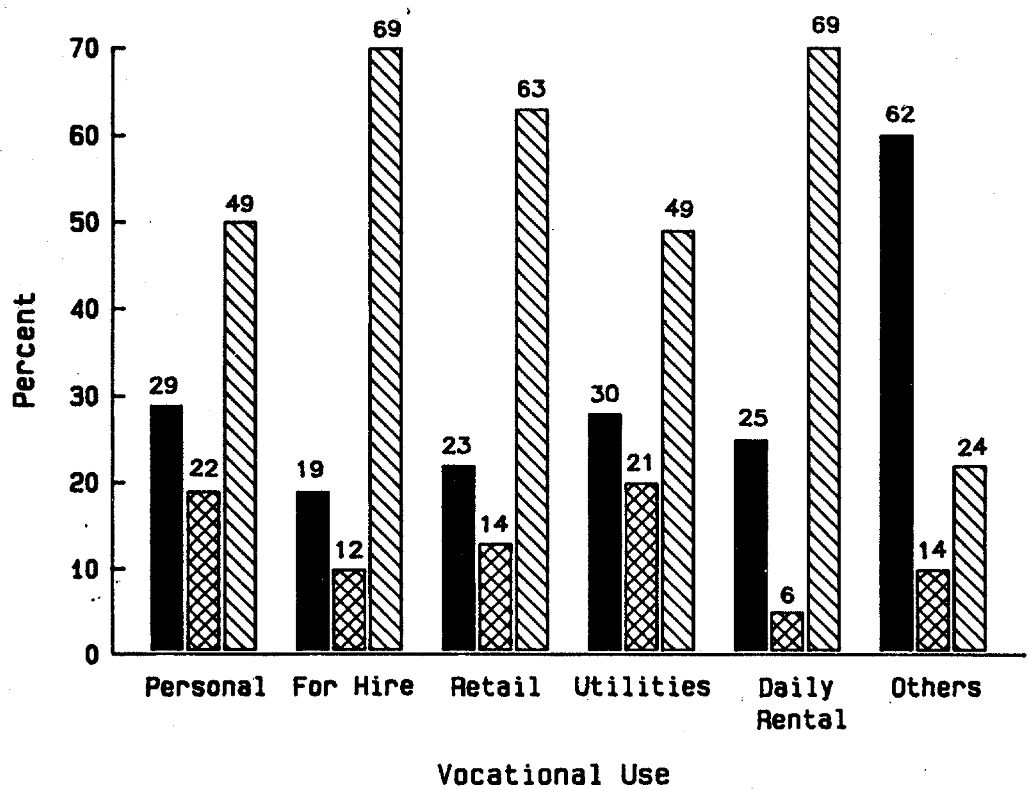
Figure 14. Vehicles and Miles Travelled by Vocational Use: Combination-Unit Trucks



SOURCE: TIUS 1982

Figure 15. Miles Travelled by Vocational Use and Fleet Size: Combination-Units





Source: TIUS 1982

VEHICLE BODY TYPES AND THEIR USE PATTERNS

Most combination-unit trucks are used in long haul operations, much of it presumably on the Interstates. Nevertheless, an equally significant portion of their mileage is accumulated on shorter distance trips, many of which are likely to be made on open access, undivided highways. Table 22 shows the distribution of how this mileage is accumulated.

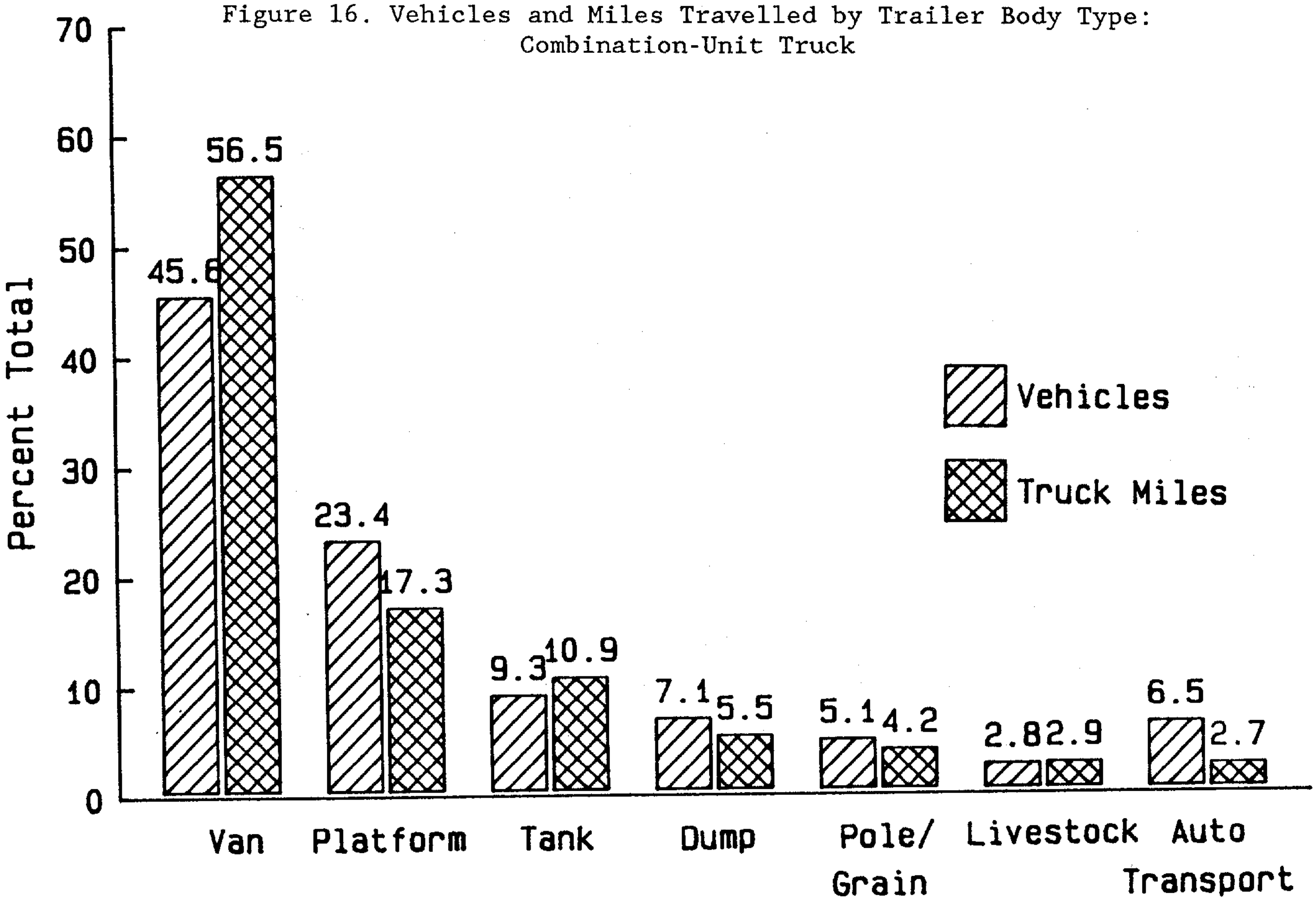
Table 22. Combination-Unit Truck Mileage by Type of Operator, by Fleet Size and Range of Operation, 1984

Type and Size of Fleets	Range of Operation: Local (> 50 miles)	Short (50-200 miles)	Long (< 200 miles)	Total
Private	8,700 (22.5%)	13,677 (35.4%)	16,292 (42.2%)	38,669 [50.3%]
Small (1-5)	2,602	3,250	3,319	9,171 [11.9%]
Medium (6-99)	5,010	7,574	7,607	20,191 [26.2%]
Large (100+)	1,088	2,853	5,366	9,307 [12.1%]
For Hire	5,054 (13.2%)	10,384 (27.2%)	22,762 (59.6%)	38,200 [49.7%%]
Small (1-5)	1,208	2,805	6,768	10,781 [14.0%]
Medium (6-99)	2,842	4,732	6,637	14,211 [18.5%]
Large (100+)	1,004	2,847	9,357	13,208 [17.2%]
Total	13,754 (17.9%)	24,061 (31.3%)	39,054 (50.8%)	76,869

SOURCE: Derived from 1984 FHWA Highway Statistics and 1982 TIUS

There are a wide variety of trailer body types used in combination-unit trucks. Given the nature of a majority of the products hauled in trucks, it is no surprise - as indicated in Figure 16 - that van bodied trailers are the most prevalent and accumulate the most miles travelled. This fact is one of the principal reasons why van bodied combination-unit trucks account for the largest portion of the total number of accidents that occur. Four body types, vans, platforms/flatbed, tanks (liquids, gases, and dry bulk), and dump account for the majority of vehicles and mileage. As discussed in Section 2, these same four body types account for the majority of accidents as well.

Figure 16. Vehicles and Miles Travelled by Trailer Body Type: Combination-Unit Truck

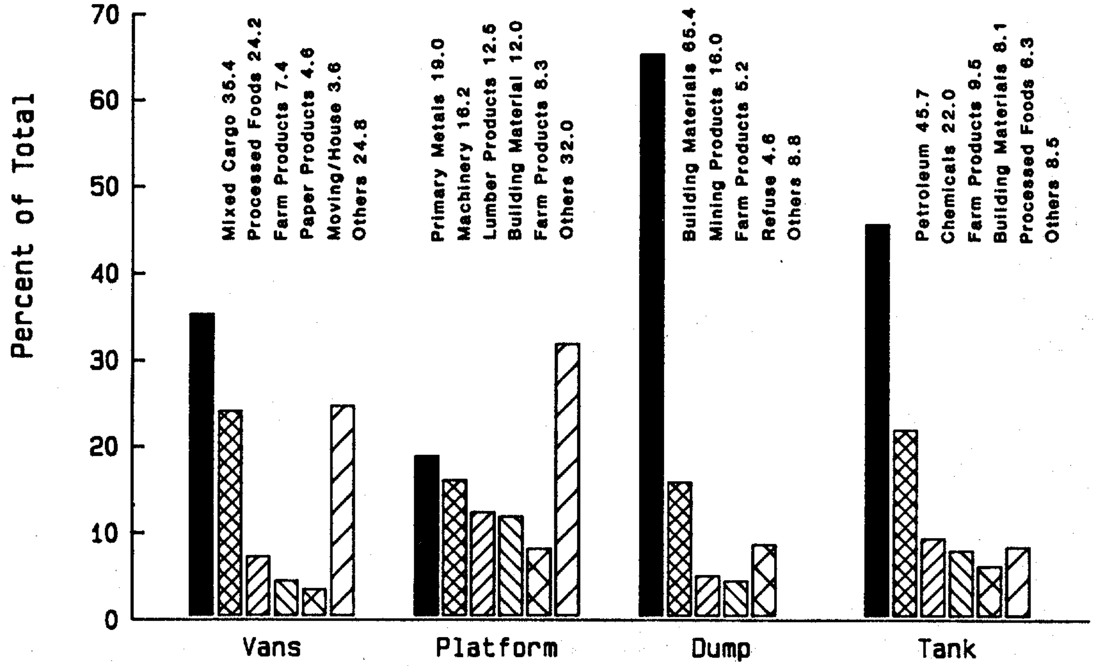


SOURCE: TIUS 1982

The choice of a given trailer type is obviously very much dependent on the nature and type of commodity being hauled. Figure 17 shows the total mileage accumulated by each of the four combination-unit truck body types as a function of the commodity being hauled. In most cases, it is self-evident as to why a given trailer body type is chosen for a particular commodity. Information about these commodities (e.g., density, c.g. height, dynamic sloshing properties, etc.) helps in better understanding the stability properties of some of the vehicles and therefore some of the potential underlying causes of their accident patterns.

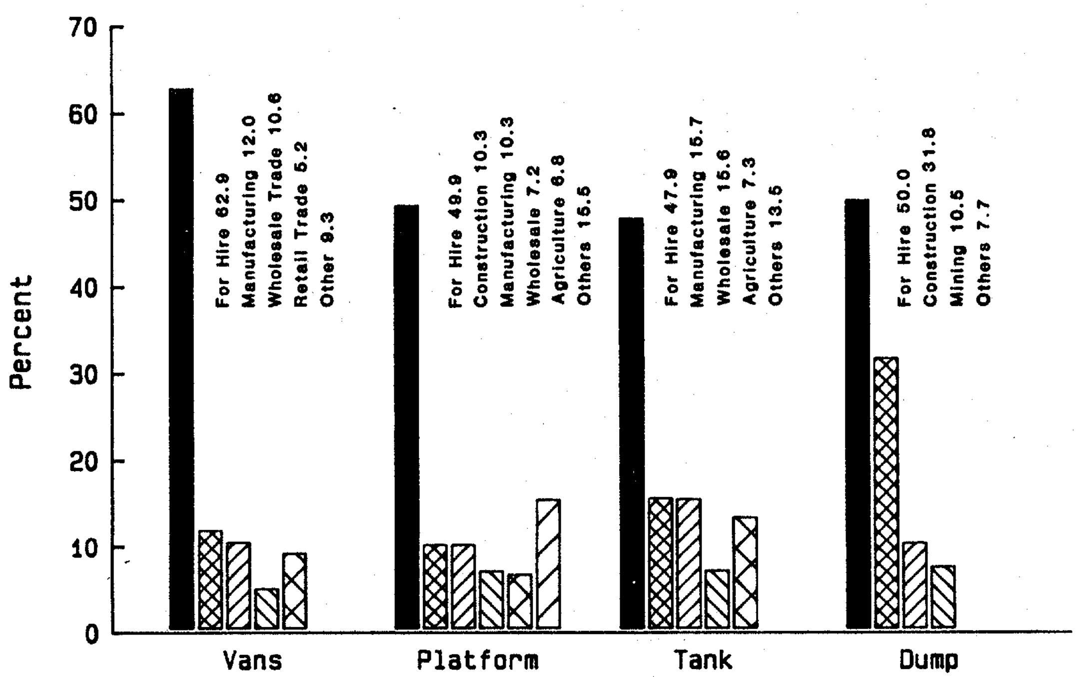
For hire fleets predominate in the use of almost all vehicle body types. Beyond this level of understanding, however, it is instructive to note (as can be seen in Figure 18) that for vehicles other than vans, other vocational uses (namely, construction, wholesale and retail trade, manufacturing, and mining) accumulate significant portions of the total combination-unit truck mileage. The degree to which these other users operate their vehicles on highway types that present greater accident risks needs to be better understood.

Figure 17. Distribution of VMT for Each Combination-Unit Truck Body Type by Commodity Being Hauled



SOURCE: TIUS 1982

Figure 18. Distribution of VMT for Each Combination-Unit Truck Body Type by Vocational Use



SOURCE: TIUS 1982

SUMMARY

Tying all this information together and then linking it directly to accident patterns is difficult. Representative, mass data are not available linking carrier related information (ie. size, vocational application, trip patterns, predominant highway types used) to combination unit-truck VMT patterns (ie. VMT by highway type, body type, vocational application, etc.), and accident patterns. Only when data of this type become available, can detailed accident rate computations be made and, therefore, highly specific questions answered relative to accident overrepresentation.

An example of the type of analysis that should be pursued in this regard is shown in Table 23. Shown are the comparative proportions of accident involvements and fatalities occurring in Texas attributable to the various body types of combination-unit trucks. Also shown are the relative proportions of the number of each body type of combination-unit truck, and their mileages, that were registered in Texas. It is recognized that vehicles other than those registered in Texas may have been involved in accidents in Texas. Nevertheless, the relative proportions shown are suggestive of possible larger trends. Collectively, these data suggest that, although vans may be involved in the most accidents, their proportional involvement may be lower than other body types because they accumulate proportionally more mileage and therefore accident exposure risk. Conversely, platforms/flatbeds, tanks, and especially combination-unit trucks with livestock trailers may be overrepresented in fatal and non-fatal accident involvements.

Table 23. Distribution of Combination-Unit Truck Vehicle Population, Mileage, and Accident Involvements by Body Type, in Texas

Body Type	Percent of Vehicle Population	Percent of Miles Traveled	Percent of Vehicle Involvements In Accidents	Percent of Combination-Unit Truck Driver Fatalities	Percent of "Other Vehicle" Driver Fatalities Occurring in Collisions W/ Combination-Unit Trucks
Van	38.4	45.5	32.3	28.1	24.5
Platform	29.1	22.2	25.1	25.2	27.8
Tank*	12.6	15.0	20.7	33.0	20.8
Dump	6.9	7.3	10.2	3.0	11.1
Pole/Log	1.8	1.2	2.2	0.7	1.9
Livestock	0.9	1.3	6.4	6.7	8.0
All Others	10.3	7.2	3.1	3.3	5.9
Total	100.0	100.0	100.0	100.0	100.0
	[89,476]	[4,800 million]	[21,385]	[135]	[435]

SOURCE: TIUS/Texas 1982 and Texas State Accident Data (1981-1983)
* Includes dry bulk,liquid, and gas

The data and discussion presented here, should serve to indicate that the medium and heavy truck accident "problem" is not simply addressed by dealing with only one or even several variables that can effect accident patterns. The true causes of truck accidents lie as much in patterns of exposure to the likelihood of having an accident as they do in factors which actually trigger the occurrence of an individual accident.

Accident exposure patterns are very much tied to the nature of individual trucking operations. These are diverse and complex and need to be better understood before effective strategies and programs can be developed to deal with the overall issue of truck safety.

SECTION 4. VEHICLE DYNAMIC PERFORMANCE

INTRODUCTION

On May 2, 1985, within two hours and sixty miles of each other, five people were killed in two separate, but very similar collisions with combination-unit trucks, one in Maryland, the other in Virginia. All the victims were passengers in the other vehicle involved in these accidents. One was an eleven month baby and both his parents. Neither truck driver was injured. The accident scene for the Maryland accident is shown in Figure 19, while the Virginia accident is shown in Figure 21. The passenger vehicle involved in the Maryland accident is shown in Figure 20, while the one involved in the Virginia accident is shown in Figure 22.

The first significant rainfall in approximately four weeks was falling at both sites, so the roads were slippery. Both the trucks involved were traveling empty. Neither truck was exceeding the speed limit on the two lane undivided roads on which they were traveling. In one case, the road was straight and level; the other , downhill and curved to the right. Both trucks were following other vehicles in the traffic stream.

Neither truck had front wheel brakes. This is not uncommon among today's combination-unit truck fleet, nor was it illegal at the time of these accidents. The rest of the trucks' brake systems were fully operative. In fact, one truck's brakes had been adjusted the day before the accident. (The Federal Motor Carrier Safety Regulations (FMCSR) were revised January 27, 1987 to ensure that all trucks originally designed to have front wheel brakes (required by NHTSA for new trucks since 1980) in fact have them and that they are operational.)

In both cases, the accident began when the truck encroached into the oncoming lane of traffic where the other approaching vehicle was struck before it could take any evasive maneuvers. In the Virginia accident, the tractor jackknifed, placing the tractor directly in the path of the oncoming vehicle; in the Maryland accident, the trailer swung out to the left, placing the trailer's wheels and tires and the side rail of the trailer's floor structure in the oncoming vehicle's path.

In both cases, the collision was preceded by the truck driver making a brake application to slow his vehicle, resulting in his losing control of the vehicle. In neither case could or did the truck driver perceive or react in time to the loss-of-control that his brake application precipitated.

Figure 19. Schematic for accident in Maryland

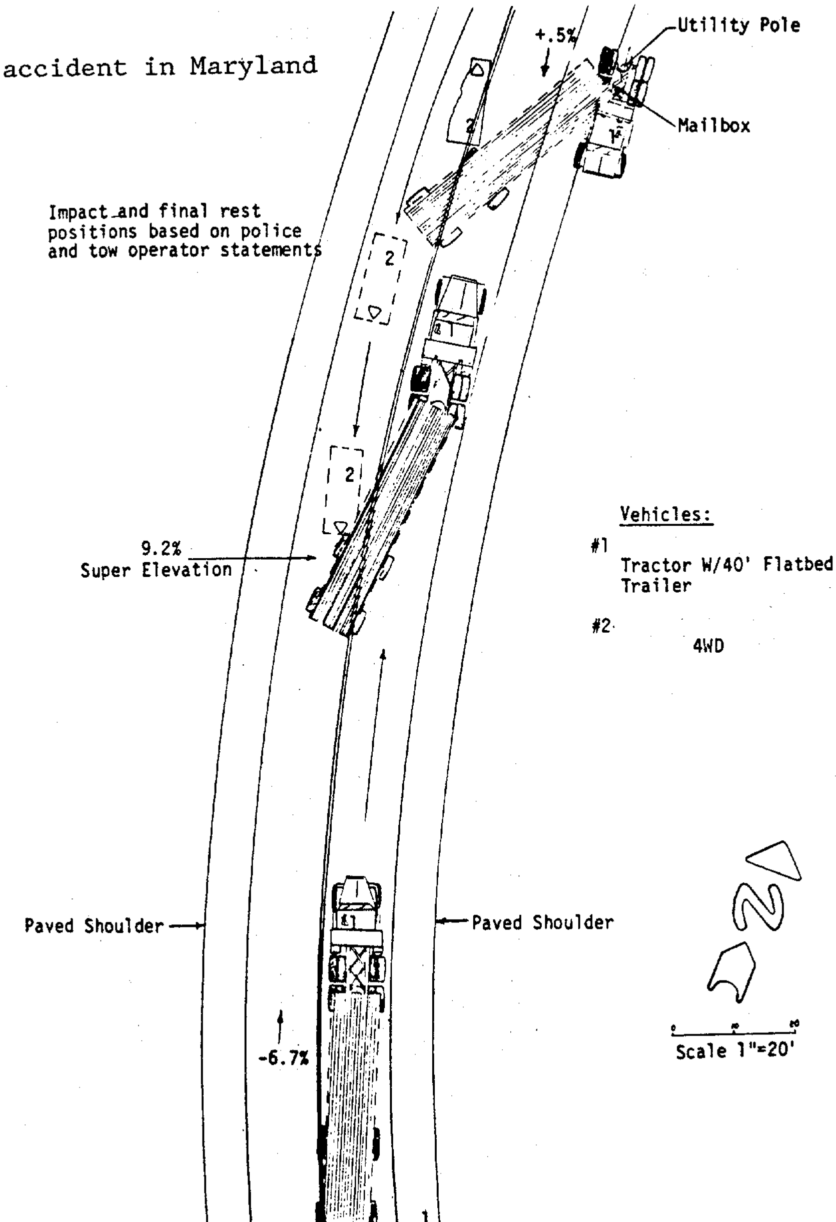


Figure 20. Passenger Vehicle Involved in Maryland Accident

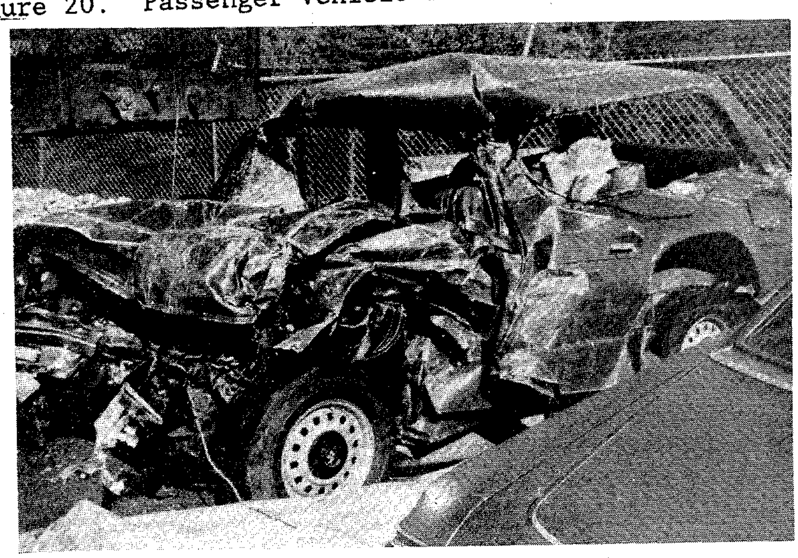


Figure 21. Schematic for Accident in Virginia

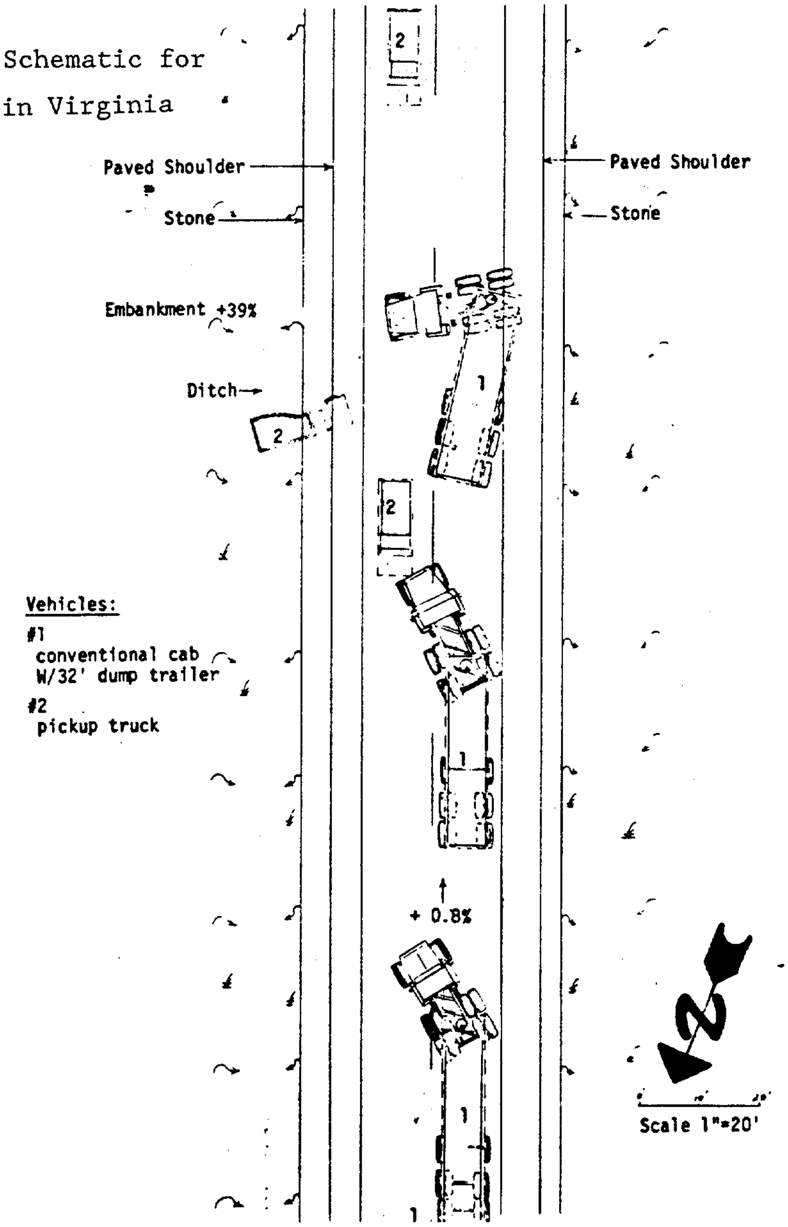


Figure 22. Passenger Vehicle Involved in Virginia Accident

One of the two drivers, interviewed later, stated that his brake application was not "...an especially severe one..." but that "...things happened so fast I didn't have time to react. I've never been in a situation like that before, every other time I made a hard stop like that, I've had a load on and it didn't jackknife".

Both these accidents, and their tragic consequences, highlight some of the reasons why heavy truck accidents have become a frequent front page headline issue in so many areas. The facts surrounding these two accidents are symptomatic of many of the underlying safety problems facing the heavy truck manufacturing and user (motor carrier) industry today. They can be summarized as follows:

Truck Driving Behavior Issues

* Conventional wisdom relative to the safe driving of a heavy truck dictates that the vehicle be operated well below the limits of its safe operating performance range. This is generally termed "defensive driving," and by-and-large it is very successful, most of the time. Typical truck driver training does not prepare nor equip drivers to successfully cope with the fast-acting bad response characteristics of their vehicles. This creates a situation wherein drivers must attempt to make maneuvers, or cope with an incipient loss-of-control, for the first time, typically just before becoming involved in an accident.

* Bad driving behavior by either truck drivers or others operating in close proximity to the truck is especially risky. It places the vehicle close to the limits of its safe operating range, greatly reducing margins for even slight errors by either the truck driver or other drivers operating nearby.

Truck Design Performance

* Under some routinely encountered operating conditions, heavy trucks have a propensity for loss-of-control at threshold levels significantly below those of the other vehicles with which they share the highway.

* Under lightly loaded or empty conditions, and especially on wet or slippery roads, heavy trucks have a strong tendency to jackknife or spin if a "hard" accident-avoidance maneuver is attempted.

Vehicle Use Issues

* Because of the functional uses to which they are typically applied, heavy trucks operate a significant portion of their time on the higher speed roadway types (i.e. Interstates, U.S. Routes, and State Routes). With the exception of the Interstates, much of this exposure is on two lane undivided roads, facilities not particularly well suited to the truck's dynamic stability tendencies, and not at all forgiving of errors by their drivers. Because of speed and the size of the vehicle the outcomes of accidents on these type of facilities tend to be severe.

* As traffic densities and congestion increase on urban/suburban freeways and arterials, the opportunity for conflicts between heavy trucks and smaller vehicles increases. Defensive driving strategies by truck drivers may not be sufficient to compensate for the actions of other drivers, leading to a situation where the truck's operating characteristics and use patterns become even more critical than they now are.

This section of the report addresses several of the factors characteristic of heavy trucks in braking and steering maneuvers.

As with all motor vehicles, driver control of medium/heavy trucks is limited to braking, acceleration and steering inputs. Any or all of these control applications are utilized to operate the vehicle under routine conditions or in the attempt of non-routine, often severe, avoidance maneuvers when the driver is confronted with a potential crash threat. In the case of most four-wheel vehicles, comparatively severe levels of either steering or braking must be made to induce dynamic instabilities in the vehicle. This is not the case with medium/heavy trucks. These vehicles are susceptible to rollover, spin-out and jackknife even in much less severe turning maneuvers. Typical passenger cars, for example, can successfully execute cornering maneuvers on dry pavement that require 0.8-0.9 g's of lateral acceleration. By comparison, many fully-loaded trucks became unstable during cornering at 0.3-0.4 g's of lateral acceleration.

There are many vehicle-related reasons for these differences. One important factor is the load that can be carried by heavy trucks and the resultant wide variation in vehicle weight between the empty and fully loaded conditions. This ratio of loaded to unloaded weight is typically 1.3:1 for a passenger car, but can be as large as 3:1 for a combination-unit truck Also, the center of gravity is much higher above the ground -- 4-7 feet for a truck compared to less than 2 feet for a passenger car. These two properties along with the vehicle's width, length, and the fact that they articulate, challenges the truck designer to select and match brake systems, tires, suspensions, frames, etc., that operate stably for all potential conditions of use. These components, which play a significant role in determining the dynamic performance of heavy vehicles, are generally specified for the purpose of optimizing productivity, efficiency, and durability.

The stability and control characteristics of heavy trucks are direct indicators of their safety performance. This is because the driver's ability to control his vehicle -- that is, his ability to make it go in the direction he chooses at the speed he chooses -- is ultimately limited by the response of the vehicle to steering and braking inputs. It follows, therefore, that limitations in the dynamic control capabilities of heavy trucks serve not only to limit the viable options which are open to the truck driver in maneuvering to avoid traffic conflicts produced by other vehicles, but, also to reduce the tolerance which is available to compensate for any inappropriate control inputs made by the driver. In effect, the vehicle becomes less forgiving of control errors. In certain cases, increased accident probability can be shown to correlate very closely with certain measures of stability and control performance.

The ultimate criteria for judging the stability and control performance of a motor vehicle is whether or not the vehicle's driver can maintain stable control under all intended and foreseeable conditions of operation. In this regard, one can consider that the expectation of good dynamic behavior is fulfilled when the vehicle:

- Attains a desired deceleration level during braking,
- Follows a desired path in response to steering,
- Remains upright (i.e., does not roll over),
- Maintains a limited swept path, and
- Does not oscillate from side to side in an uncontrollable manner.

In practice, medium/heavy vehicles often fail to meet these desired criteria for a variety of reasons. Within the current state of knowledge, considerable progress has been made in identifying both the relatively modest levels of control input which can cause truck instability, and the instability modes choices or patterns of design, maintenance and operating practice -- factors which are, in general, amenable to change.

The following are critical limitations to the safe design and operation of large vehicles with respect to their directional and braking performance.

- Poor wheels-unlocked stopping performance. This results primarily from the general mismatch between the brake torques developed at each wheel and the prevailing wheel loads. This mismatch occurs due to the tremendous changes in wheel loading (both static and dynamic) that take place as a result of payload weight and placement. In addition, brakes often fail to deliver their designed torque output because they are not properly adjusted.

- Poor retention of braking capacity during descent of long and/or steep grades. The braking horsepower necessary for a fully-loaded vehicle to safely descend a substantial grade at highway speeds places a large demand on capacity of most truck brake systems. Parasitic losses which would normally aid in slowing the vehicle are low relative to the total vehicle weight. The search for improved fuel economy continues to reduce these parasitic losses even further.

- Loss of directional control. Exceeding the vehicle's yaw stability limit results in vehicle spin-out (single-unit trucks), jackknifing or trailer swing (combination-unit trucks) conditions. The primary cause of these phenomena is the rearward bias of braking forces typical in the brake system designs of U.S. medium/heavy trucks. This increases the probability of rear wheel lockup. Another factor is the loss of tire side force capacity when lockup occurs. Unstable yaw response in a medium/heavy truck is likely to generate turning responses which exceed the vehicle's roll stability limit, thus precipitating a rollover.

- <u>Straightforward vehicle rollover</u>. Attempting turning maneuvers at too high a speed results in the vehicle's roll stability limits being exceeded.

- "<u>Crack-the-whip" response characteristics of multiply-articulated vehicles (doubles,triples and certain truck-full-trailer trailer combinations</u>). Combination-unit vehicles often have dynamic modes of behavior which are stable under most circumstances; but, which may be very lightly damped. Multiply-articulated vehicles, have a tendency for the rearmost unit of the vehicle to show exaggerated or amplified response relative to the towing unit in certain types of severe turning maneuvers. "Rearward amplification" has important safety consequences when, during such maneuvers, the rearmost trailing unit exceeds its own roll stability threshold and rolls over.

THE PERFORMANCE CHARACTERISTICS OF MEDIUM AND HEAVY TRUCKS IN MANEUVERS INVOLVING BRAKING

<u>The Size of the Brake-System Related Safety Problem</u>

In 1984, nearly 383,000 medium and heavy trucks were involved in accidents. These accidents resulted in the deaths of 5,657 persons. As discussed in Section 1, numerous factors play a contributing role in causing accidents; it is rare when accidents are attributable to a single cause. Nevertheless, people associate the cause of many of these accidents to problems related to truck brake system performance. An attempt is made here to estimate the "target" accident problem size -- i.e., that portion of the medium/heavy truck crashes that could be influenced by improvements to the vehicle's braking system.

There are basically four different types of truck accidents that could be related to braking system performance:

- Accidents due to failed or inoperative brakes

- Runaways on down grades,

- Accidents where the vehicle was unable to stop in time (brakes did not fail nor were they ineffective due to heat but they simply did not provide the stopping force necessary to avoid the accident), and

- Skidding or loss-of-control accidents where wheels locked during braking.

Each of these four categories will be discussed individually although it is possible that some accidents may have involved two or more of the above situations simultaneously. Improving brake system performance would not guarantee that all of these accidents, or a specific portion of them, could be eliminated.

Brake Failures or Inoperative Brakes

In spite of the fact that, historically, roadside inspections conducted by both Federal and State officials have found brake system condition and maintenance to be poor (see Table 24), few accidents are reported to be caused by deficient or inoperative brakes.

Table 24. BMCS Roadside Inspection Results

Inspection Results	Year 1983-84	1973 (6 months)	1966
Number of Vehicles Inspected	43687	18169	31749
Proportion of Vehicles Placed Out of Service For Vehicle Deficiencies	22.9%	21.3%	21.7%
Proportion of Out of Service Deficiencies Which Were Brake-Related	68.2%	58.7%	67.7%

SOURCE: BMCS

It should be noted, however, that most accident reports that cite brake deficiencies or failures only do so when a brake system component has obviously failed or is otherwise non-functional (by visual inspection). Brakes that are out of adjustment or have insufficient retardation capability for other reasons are not likely to be detected and therefore are not considered failures or deficiencies for purposes of these types of reports.

BMCS data, for example, have historically indicated that less than 2 percent of the accidents reported to them are directly attributable to mechanical deficiencies in the braking system (see Table 25).

Table 25. Brake Failure/Deficiency Accidents, BMCS

Year	Number of Brake Related Accidents	Percent Total Accidents
1983	476	1.5
1982	437	1.4
1981	455	1.4
1980	458	1.5
1979	434	1.2

SOURCE: BMCS Accident Reports

Texas and Washington State accident data were reviewed for further information on this issue, since brake related problems are directly coded in these files (all alcohol, and drug-related accidents were excluded). These data are shown in Table 26.

Table 26. Estimated Number of Combination-Unit Truck Accidents Involving Deficient/Inoperative Brakes

	Texas	Washington
Number of Accidents	510	501
Percent Total Accidents	2.4	5.2

SOURCE: Texas and Washington (1981-1983)

The higher percentage of accidents in Washington and Texas which involve brake system deficiencies, compared to the BMCS data, may be due to a number of factors. BMCS accident data is based on self-reports made by truck owners rather than impartial investigators such as police or Federal or State inspectors. Truck owners may fail to fully investigate their accidents or may be hesitant to admit brake problems in their fleets. McDole and O'Day (1975) noted that 2.9 percent of the accidents occurring in the selected fleets they studied were caused by deficient brakes.

The apparent paradox between the high incidence of "brake deficiencies" observed in roadside inspections versus the low incidence of crashes involving "brake deficiencies" may be explained by the fact that brake systems are typically sized for the most demanding loading and operational conditions anticipated. Therefore, in general, vehicles have more braking capacity than is needed for routine stops and it is possible for them to function quite adequately in many situations despite having several axles' brakes either inoperative or out-of-adjustment.

Runaway Accidents On Downgrades

The annual number of downhill runaway accidents is difficult to pinpoint accurately. Fancher, et. al.(1981) estimated there are 2,300-2,450 truck runaway incidents per year, resulting in 150-300 combination-unit truck downhill runaway accidents and 25-50 fatalities.

One area not considered in the analysis by Fancher are those accidents that may occur after the vehicle has recently finished the downhill descent. Although the vehicle may not have encountered difficulty in descending the hill, brake temperatures may have risen to the point where the vehicle does not have the stopping capability available for resolving traffic conflicts that may occur later. Research indicates that high brake temperatures may remain for 20 minutes or more after the grade descent is completed.

Inability to Stop in Time

This is the elusive group of accidents that are often thought of as being preventable, "...but for the lack of a few feet of stopping distance." In these cases, it is generally assumed that the truck's brakes function, but because they could not stop the vehicle quickly enough, the accident occurs anyway. This is the class of accidents that some argue would be reduced if truck stopping distance performance was improved to match that of passenger cars. It is further theorized that even if the accident is not totally prevented, improvements in stopping distance performance would reduce the speed at which trucks collide with other vehicles, thereby reducing accident severity.

To study this issue, Texas accident data were again reviewed relative to this potential accident causation factor. Since "inability to stop in time" is not a coded variable in accident data bases, surrogates need to be utilized. The following types of accidents were assumed to potentially involve this factor (again, all alcohol, and drug-related accidents were excluded):

- o Collisions with other motor vehicles in which the front of the truck was involved AND the vehicles were travelling in the same direction or approaching at angles AND the damaged portion of the other involved vehicles was anything other than its front (implying that it could not have been the striking vehicle and, therefore, that the truck had to be).

- o Accidents wherein the truck was known to be attempting to slow down for any of a number of reasons (e.g., a flagman, traffic control device, another accident, etc.) AND the front of the truck was damaged.

The outcomes of these types of accidents include injury consequences to both truck occupants and the occupants of the other vehicle involved. In most cases it is likely the other vehicle occupant who sustains injury.

Based on that analysis, the following proportions of accidents are estimated to have involved trucks' inability to stop in time as a contributory factor:

Table 27. Estimated Number of Heavy Trucks Involved in Accidents Due to Inability To Stop In Time: Combination-Unit Trucks

	Number	Percent Total Accidents
Inability to Stop in Time	5,056	23.6

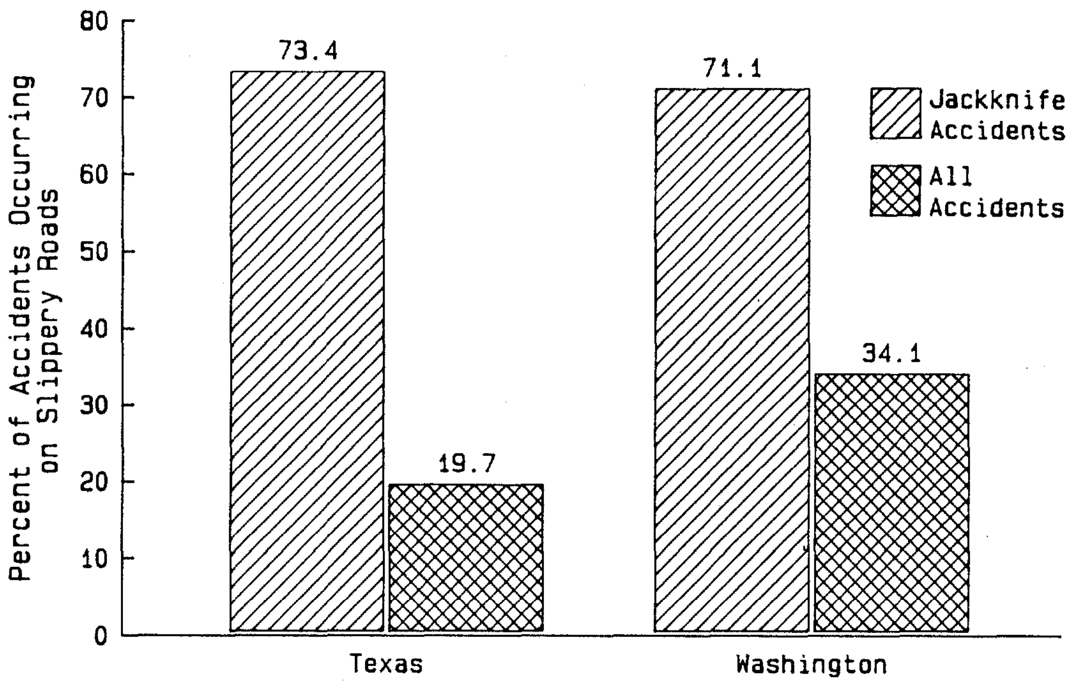
SOURCE: Texas, 1981-1983

Brake-induced Instability

This class of accidents can occur in situations when the driver is attempting to slow down or stop and in so doing locks wheels and loses control of his vehicle. Usually the vehicle is lightly loaded or empty and the road is wet or slippery. Under these conditions, the tractor jackknifes or the trailer swings out of its lane (if it is a combination-unit vehicle) or the truck spins out (if it is a single-unit) when the brake application is made.

Jackknife accidents occur under all types of road conditions, but as the data in Figure 23 indicate, it most frequently occurs when the road is wet or slippery.

Figure 23. Highway Environment Conditions Associated with Jackknifing Accidents in Combination-Unit Trucks

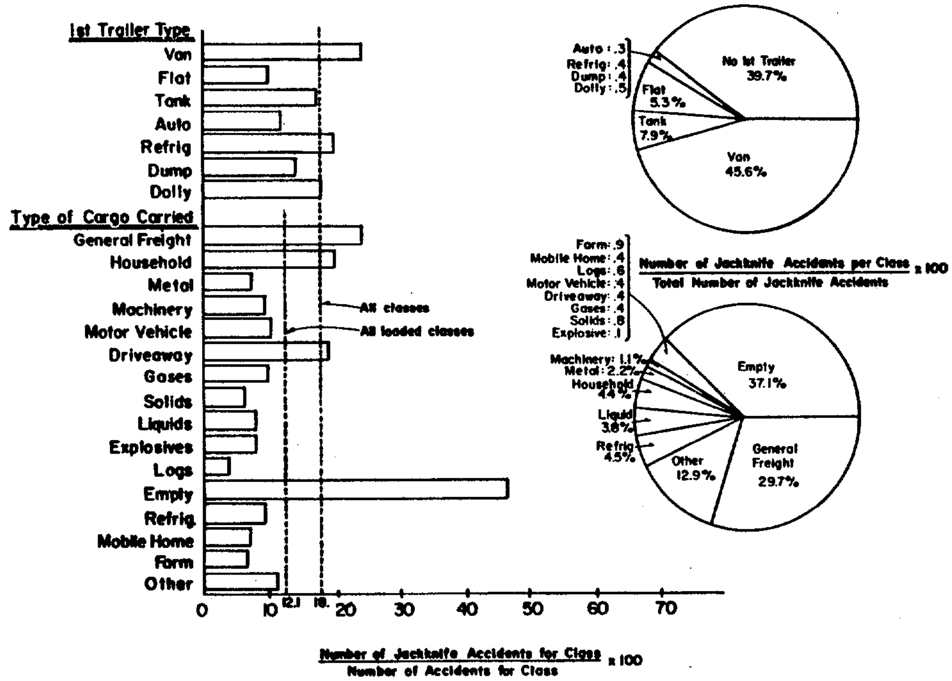


SOURCE: Texas and Washington, 1981-1983

Jackknifing is especially prevalent among lightly loaded or empty vehicles as the data developed by Winkler, et. al.(1983) indicates (see Figure 24.)

In an effort to quantify the extent of the brake-induced instability problem, Texas and Washington State accident data were reviewed relative to this potential accident causation factor. The

Figure 24 . Distribution of Jackknife Accidents



SOURCE: Winkler, et. al., (1983)

following types of accidents were assumed to potentially involve this factor (as before, all alcohol and drug-related accidents were excluded):

- o Jackknife accidents.
- o Accidents involving loss-of-control.
- o Accidents on two lane roads, under slippery road conditions, in which the truck crosses over into the oncoming traffic lane and strikes another vehicle. (The accidents described in the introduction to this section are examples of this type of accident. These two accidents were obviously brake related but were not recognized by the police who filled out the accident report).

The results of the analysis are shown in Table 28.

Summary

Although logic and engineering performance data would argue that most of the improvements that could be made to truck brake systems -- e.g., improved compatibility (pneumatic timing balance and brake force balance) between tractors and trailers, braking proportioned to the load on the axle, improved brake adjustment, systems to keep wheels from locking, etc. -- should be effective in reducing or eliminating brake-related accidents, it is difficult, and in some cases impossible, to demonstrate this with accident data. This is especially true when dealing with the "inability to stop in time" portion of the accidents, since other contributing factors often are present and are more apparent to the investigating personnel. As a result accident analysis findings tend to be indicative rather than conclusive.

Table 28. Estimated Heavy Truck Accidents Due To Brake-Induced Instability: Combination-Unit Trucks

Type of Accident	Texas	Washington
Jackknifing		
Number	705	373
Percent Total Accidents	3.2%	3.8%
Loss-of-Control		
Number	658	745
Percent Total Accidents	3.1%	7.7%
Slippery Road Collisions in Other Vehicle's Traffic Lane		
Number	547	--*
Percent Total Accidents	2.6%	--
Total Number of Accidents**	1,743	960
Percent Total Accidents	8.7%	11.9%

SOURCE: Texas and Washington, 1981-1983
* Not available from Washington file
** These categories are not mutually exclusive and therefore are not directly additive.

For example, a recent German paper (Otte, et. al. (1986)) documents an analysis of 182 commercial vehicle traffic accidents involving injuries. Of these accidents, 161 involved medium/heavy trucks. The sample included 82 single-unit trucks and 79 combination-units. Of these accidents, 43 percent of the braking efforts were found to result in some wheel lockup and 22 percent of the vehicles became unstable. A multi-disciplinary research team, comprised of members from the Hanover Teaching Hospital and the Berlin Institute of Technology, analyzed these accidents in detail to assess the influence that devices for preventing wheel lockup might have had on these accidents.

They found that 7.1 percent of the 182 accidents could have been completely avoided if the commercial vehicles had been equipped with antilock brake systems. In the case of combination-unit trucks, 10 percent of their accidents could have been completely avoided (this represents 24.5 percent of those accidents which combination vehicles had which resulted in wheel lockup).

In addition, the researchers found that the addition of a device to eliminate wheel lockup would have avoided or reduced:

o 13.9 percent of the property damages to the commercial vehicles,

- o 17.4 percent of the injuries to occupants of the commercial vehicles,

- o 11.1 percent of the property damages to others involved in the accidents,

- o 10.8 percent of the personal injuries suffered by others involved in the accidents.

Since only accidents resulting in personal injuries were investigated, the percentage of avoidable accidents would be expected to be higher for less severe crashes resulting in material damages only.

Similar conclusions can be drawn from the results of the analyses performed for this study. They are summarized in Table 29. Collectively, these data indicate that the portion of all truck accidents that potentially have brake system issues as a contributing factor could be as much as one third. These findings indicate that brake-related problems are large enough to warrant considerable attention.

Table 29. Estimated Proportion of Combination-Unit Truck Accidents Involving Brakes as a Contributing Factor

Accident Type	Number of Accidents	Percent Total Accidents	Combination Unit Truck Drivers Killed or Injured	Percent Total Truck Drivers Killed or Injured	Drivers Of Other Vehicles Killed or Injured In Collisions With Comb. Unit Trucks	Percent Total Other Drivers Killed or Injured
Deficient/Inoperative Brakes	476-510*	1.5-5.2*	28**	1.6**	34	1.2
Inability To** Stop In Time	5056	23.6	208	12.2	678	24.9
Brake Induced Instability	960-1743+	8.7-11.9+	190-260+	11.1-27.8+	240**	8.8**
Runaway++	150-300	< 1.0	50-100	< 1.0	--	--

SOURCES: * BMCS 1983/Texas 1981-1983/Washington 1981-1983/McDole and O'Day 1975
** Texas 1981-1983
+ Texas 1981-1983/Washington 1981-1983
++ Fancher 1981 (National estimates)

Vehicle Braking Performance -- Design and Use Considerations

Introduction

Truck brake system design involves a complex set of considerations and trade-offs not faced in the design of other vehicles. This is especially true in the case of combination-unit trucks. These considerations can be grouped as follows.

- Overall Brake System Capacity -- Truck brakes must be sized to handle vehicle loaded weights which can be as much as 3 times higher than empty weights. In passenger cars, this ratio is typically only about 1.3. Several problems can arise as a result of the compromises that must be made to accommodate not only the maximum weight of the vehicle but also the range of weights over which it can be operated. In addition, heavy trucks roll much easier than passenger cars, not because of their weight, but because their parasitic drag (aerodynamic drag, rolling resistance, etc.) is lower with respect to their weight. This places additional demands on truck braking systems, particularly in braking situations requiring repeated or continuous use.

- Brake Force Distribution -- Ideally when a vehicle is braking, each axle and tire does a share of the overall braking that is proportionate to the load that is on the axle. Under limit performance, maximum braking effort conditions, it is especially difficult to accomplish this on heavy trucks -- particularly combination-units.

- Timing -- In order to achieve minimum stopping distance when making maximum braking effort stop, brakes must apply as quickly as possible. They must also release as quickly as possible so that a driver can quickly regain control in the event he locks wheels, and starts to skid. In addition, trailer brakes must not be significantly slower applying than tractor brakes; otherwise, trailer overrun and pushing force are created. The goal is to get as close as possible to simultaneous activation and release of all brakes in a combination-unit truck.

- Compatibility -- Truck tractors and the semitrailers and trailers they pull must be compatible with each other in terms of the amount of braking each does. Because tractors and trailers are manufactured separately, broad ranges of performance exist for each of these variables, some of which are not compatible with each other.

- Practicality -- While optimum limit performance capability is obviously a desirable feature to have in an accident avoidance situation, these conditions are, hopefully, rarely faced if the vehicle is driven prudently. Thus, the more pressing objectives to be met in brake design are to provide systems which are reliable, durable, comparatively inexpensive, easily maintained, and which function well in routine stopping situations. The systems that have evolved meet most of the objectives fairly well. Because truck brake systems have a great deal more braking capacity than is required to make most routine stops (even under loaded conditions), it is possible for them to function quite adequately in many situations despite having several axles' brakes being either inoperative or out-of-adjustment. Problems only arise when the vehicle has to make a brake application that results in wheel lockup or while negotiating steep downgrades. Balancing these rarely encountered safety concerns against more readily apparent functional and operating objectives is always difficult, especially since many of the solutions to improve limit performance capability add to the complexity and cost of the brake system.

Each of these issues, then, needs to be considered in the context of safety problems that can arise and the difficulties faced in designing a braking system that satisfactorily meets all the functional objectives as well. From a purely safety perspective, the compromises that have evolved have not always been the best ones. Truck brake systems have a number of critical limitations, namely:

- Inadequate Capacity in Continuous or Repeated Braking Situations -- The capacity of truck brakes systems has not increased to match the increasing demand placed on them as a result of fuel economy enhancement efforts to decrease parasitic drag. As a result truck drivers must compensate even more than in the past and must drive their vehicles much differently than passenger cars when descending grades. Lower descent speeds (and lower transmission gear ranges) must be used to prevent runaways.

- Poor Brake Distribution -- U.S. trucks and combination-units typically have a strong rearward bias in the application of braking force. Front wheel/steering axle braking is usually low. This results in limit performance stopping distances which are longer than other vehicles. Additionally, combination-unit trucks can easily become unstable due to locked wheels under many brake application conditions.

- Incompatibility of Tractor and Trailer Brake Systems -- Many tractor and trailer brake systems are not compatible. Often, the amount of braking force being applied by the tractor's axles greatly exceeds that of the trailer's, or vice versa. Similarly, the brakes may apply or "come on" quicker on the tractor than on the trailer. Incompatibility compromises vehicle stability and brake effectiveness, and can cause uneven brake wear problems. It can also cause brake fade on downhill descents. In addition, brakes on trailers often apply and release slowly compared to those on the tractor. This is due to the distance between the brake control valve (treadle) and the trailer brake valve(s). Slow brake application times increase stopping distance and slow release times make it difficult to recover quickly from trailer wheel lock up should this occur. This problem is more pronounced with longer combinations.

- Sensitivity to Brake Maintenance -- Because truck brake systems are more complex and experience comparatively more severe service conditions than passenger car brake systems, they require a great deal more maintenance. Brake part failures are common under fleet-service operating conditions. Frequent inspections and repairs must be made to assure that systems are operating and are properly adjusted (since, unlike passenger car brake systems, most truck systems do not self-adjust with wear). The need for a great deal of maintenance is a significant problem since roadside inspections have, for many years, indicated that many operators do not adequately perform it. Additionally, many replacement parts such as valves and brake linings do not exhibit comparable performance to the parts that were originally installed, thereby creating compatibility problems when repairs are made.

Each of these issues is addressed in detail in the following discussions.

Brake System Capacity

An obvious problem facing the medium/heavy duty vehicle brake system designer is the sheer weight of the vehicle. With gross weights permitted by Federal law to reach 80,000 lbs (with some states permitting considerably greater weights) heavy duty vehicle braking systems must be capable of slowing and stopping the vehicle in distances that are compatible with much lighter weight vehicles. Heavy vehicles simply must have considerably bigger brakes to control their mass which can exceed that of a passenger car by a factor of 30 or more. When adequately maintained, most heavy trucks built today can generate sufficient brake torque to lock (or come relatively close to locking) all their wheels except those on the steering axle on all road surfaces at all loading conditions. If a brake is "big" enough to lock a wheel, the issue of stopping ability of that wheel then focuses on tire properties and not the brake since, in effect, any further increase in braking torque cannot be utilized. The limit of tire traction in such a case determines the wheel's stopping ability. With the exception of the brakes on the steering axle, an issue which will be discussed in greater detail below, truck brakes, assuming they are relatively cool and have not been subjected to severe use, can generate more than enough torque to handle the maximum load that the axle is rated to carry.

Beyond developing adequate braking torque, it is important to provide adequate thermal capacity so that the braking system can dissipate heat quickly enough to assure adequate stopping performance in severe usage situations. This is where the truck brake designers job becomes more difficult and the adequate sizing of the braking system is dictated by more than just the mass of the vehicle.

Any brake, no matter what size vehicle it is used on, relies on the friction material in brake linings to provide stopping torque. Since the friction material converts this mechanical energy to heat, repeated or continuous use of the brakes without sufficient cooling time will result in high temperatures in the brake. High brake temperatures most frequently occur when descending a long and/or steep grade. All conventional frictional materials will, at some elevated temperature, lose torque generating effectiveness as a result of fade (drop in coefficient of friction) or disintegration.

Thermal loads on truck brake systems are increasing. Consider a vehicle descending a grade. The vehicle will accelerate unless retarding force is provided. Retarding force can come from two sources: parasitic drag and braking. Parasitic drag is caused by rolling resistance, aerodynamic drag and if the vehicle is in gear, or is equipped with a retarder, engine braking. Depending upon the slope of the grade and the gear range utilized, parasitic drag by itself may be sufficient to control the speed of the vehicle. If, however, it is not sufficient, the brakes must be applied to supplement the parasitic drag and provide the necessary overall retarding force. Parasitic drag is, therefore,an important consideration in brake system design. Table 30 shows parasitic drag for three different types of vehicles: a 3,000 lbs passenger car, a 25,000 lbs medium truck and an 80,000 lbs tractor trailer.

Table 30. Parasitic Drag for Three Different Types of Vehicles at 55 mph in Gear

Vehicle	Drag Force, lbs	Drag Force / Weight lbs/lbs
3,000 lbs Car	165	0.055
25,000 lbs Truck	950	0.038
80,000 lbs Tractor Trailer	1400	0.018

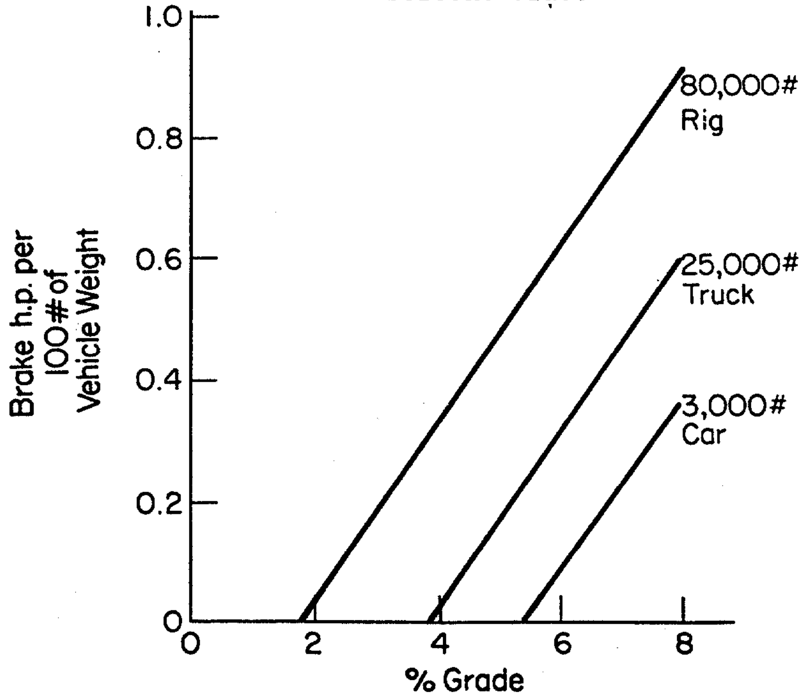
SOURCE: NHTSA/VRTC Tests

In addition to drag force, Table 30 shows the normalized drag force (i.e., drag force per lbs of vehicle weight). This is an important statistic because it removes vehicle weight from the drag force comparison. This normalized statistic indicates that an 80,000 lbs tractor trailer, has only one third the drag of a passenger car. What this means, in effect, is that the heavier truck rolls more easily than a passenger car, not because of its weight, but because parasitic drag does not increase in proportion to the weight.

Another way of looking at brake thermal loading is to plot normalized braking power required to control speed on various grades. Figure 25 shows horsepower that must be absorbed/dissipated by the braking system per 100 lbs of vehicle weight at 55 mph for the same three vehicles shown in Table 30.

What can be seen in Figure 25 is that up to a 1.8 percent grade no braking is required on the 80,000 lbs vehicle while above that level, normalized power increases linearly in proportion to the grade. On grades less than 1.8 percent, the 80,000 lbs truck's speed can be controlled at 55 mph by its parasitic drag. In comparison, the 25,000 lbs truck does not need any braking until the grade reaches 3.8 percent and the 3,000 lbs passenger car can descend grades up to 5.5 percent at 55 mph without applying the brakes. Figure 25 clearly shows that demand on truck braking systems is much greater than its weight would indicate. For example, on a 6 percent grade a 3,000 lbs car would need 0.09 hp per 100 lbs or approximately 3 hp of braking to control speed. The 25,000 lbs truck would need 0.32 hp per 100 lbs or 80 hp and the 80,000 lbs

Figure 25. Braking Power Necessary to Maintain 55 mph Versus Percent Grade



tractor would need 0.63 hp per 100 lbs or 500 hp. The tractor trailer weighs 27 times as much as the car but needs 167 times as much braking power on the 6 percent grade.

One way of measuring the reserve thermal capacity of brake systems is to compute three brake parameters which describe brake heat capacity: brake lining area per lb of vehicle weight, brake drum (rotor) swept area per lb of vehicle weight and brake drum (rotor) weight per lb of vehicle weight. These numbers can be used comparatively to guage the margin of safety afforded a particular vehicle in terms of its ability to handle the heat energy generated during downhill braking. They are shown for three different sized vehicles in Table 31.

Table 31. Brake Thermal Capacity Parameters for Three Typical Vehicles

Vehicle	Brake System Type	Parameter Per lb Vehicle Weight Lining Area,(sq in)	Swept Area,(in)	Drum (rotor) Weight,(lbs)
3,000 lbs Car	Disc Front/ Drum Rear (hydraulic)	.028	.085	.014
25,000 lbs Truck	All Drum (hydraulic)	.024	.036	.010
80,000 lbs Tractor Trailer	All Drum (air)	.025	.041	.012

SOURCE: NHTSA/VRTC Tests

One difficulty in comparing the car to the trucks is the fact that the front brakes on the car (which provide about 80 percent of its total braking force) are disk brakes. Disc brakes use significantly less lining area and usually somewhat less swept area and rotor weight than an equivalent capacity drum brake. Therefore, if the car had 4 wheel drum brakes as trucks do, the values for the car in Table 31 would have been higher. Note, however, that the values for the car are higher than those for the 25,000 lbs truck and the 80,000 lbs tractor trailer, even without this adjustment. Based on the previous discussion of parasitic drag, ideally, the heavier vehicles should have normalized thermal capacities (i.e., corrected for vehicle weight) far in excess of those for the car. Additionally, the 80,000 lbs tractor trailer should have significantly higher normalized thermal capacity than the 25,000 lbs truck. Although there is some difference in all three parameters in the right direction, the difference is not as large as the parasitic drag analysis would dictate.

Low parasitic drag is desirable from a fuel economy point of view. Less engine power is required to overcome drag; therefore, less power is needed to move the vehicle down the road. However, the relatively low normalized drag force places increased demands on the truck's braking system. These demands are likely to increase even more in the future with further attempts to make vehicles more fuel efficient. This increases the potential need, in some operational situations, for additional ways of dissipating braking heat energy.

Brake Force Distribution

In addition to ensuring that a truck's brake system is capable of generating an adequate total amount of braking force (i.e., has sufficient capacity), it is important to have braking force appropriately distributed among the truck's axles. This is important for two reasons:

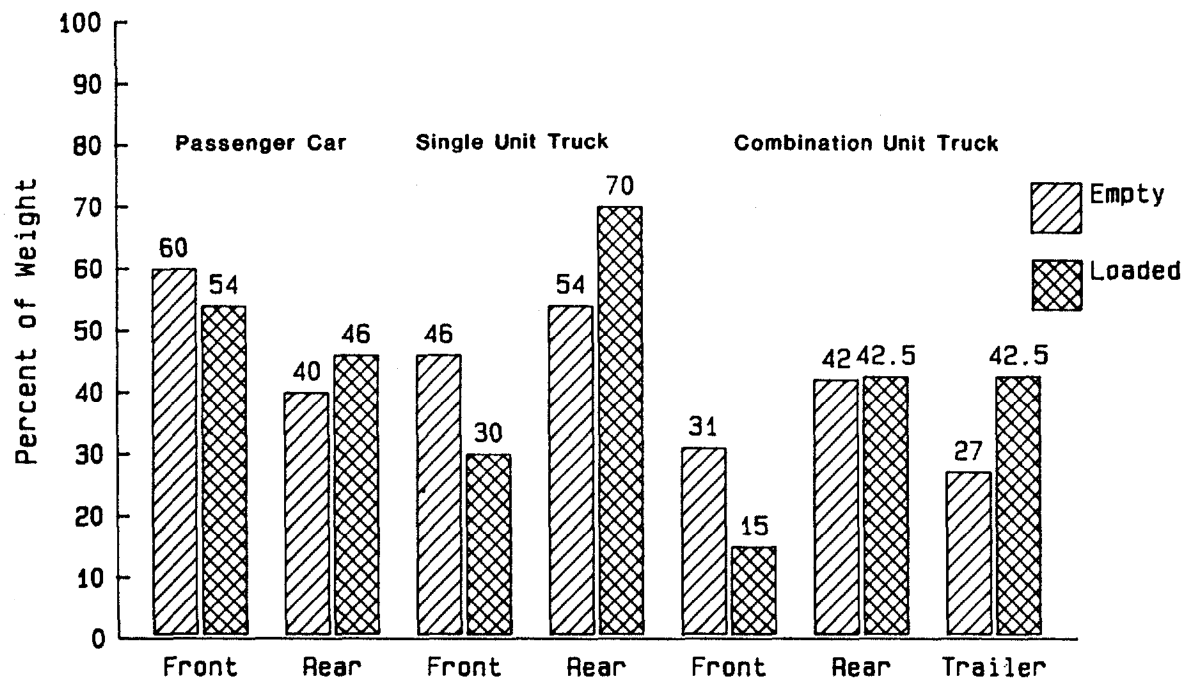
1. Under limit performance stopping conditions, if less than optimum braking force is generated at a given axle(s), the truck's stopping distance increases. If too much braking force is generated at a given axle, it locks up and the vehicle becomes unstable.

2. Under sublimit, normal stopping conditions, if one axle's brakes are doing too much braking, they will wear faster and be subject to heat build-up and fade in downhill descents.

Maximum braking effort, limit performance stops generate conditions that the brake system must handle which are greatly different than those which are encountered in normal, sublimit stops. Ideally, the amount of braking done at each axle would match the load placed on it. Unfortunately, from a braking viewpoint, this is highly variable. The amount of load on a truck axle changes considerably depending upon how much cargo the truck is carrying (static weight distribution) and how much dynamic forward transfer takes place. The other condition that arises is that as an axle is "unloaded" because the vehicle is empty or because of dynamic weight transfer, it has a tendency to lock-up prematurely (i.e., before other axles achieve maximum braking). This wheel lock-up leads to loss-of-control on the over braked axle.

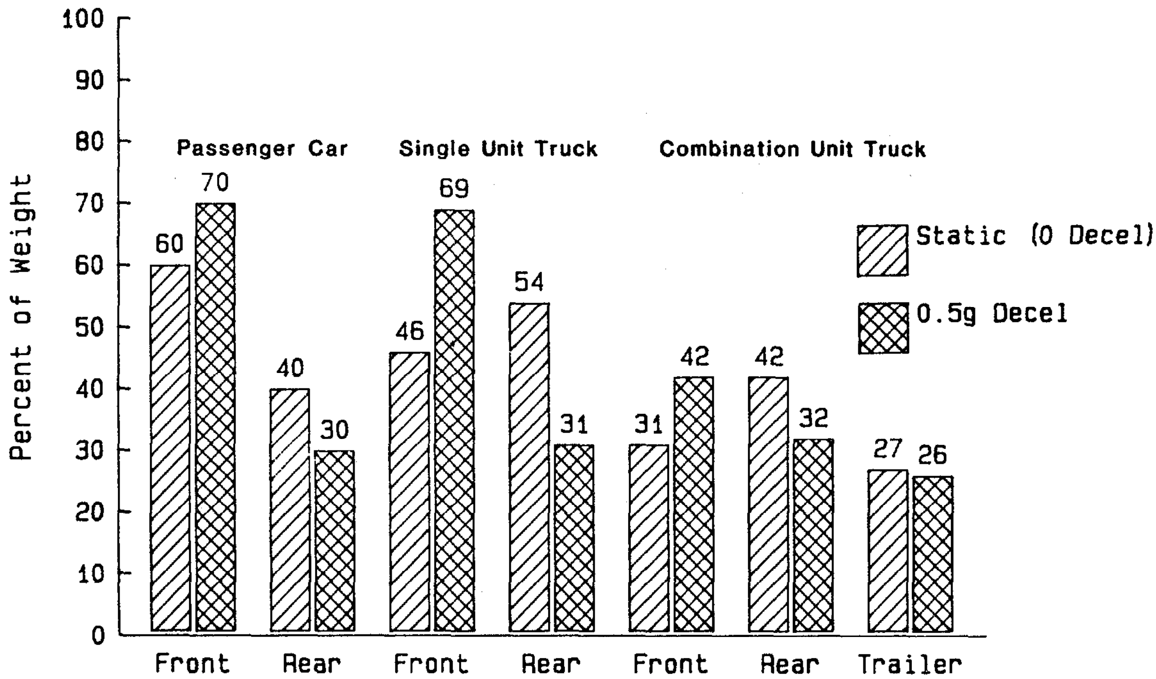
Static Weight Distribution Effect -- Figure 26 shows empty and loaded static weight distributions for a typical car, a medium duty single-unit truck (25,000 lbs GVW) and a tractor trailer (80,000 lbs GVW). It can be seen from this figure that as the vehicle is unloaded, changes in weight distribution (expressed in percentage) are much greater towards the front of the vehicle on the truck and tractor trailer than on the car. The car experiences a 11 percent increase in the portion of the total vehicle weight on the front axle when it is unloaded, whereas the single-unit truck experiences a 53 percent change and the tractor trailer experiences a 107 percent change at the front axle.

Figure 26. Static Weight Distribution for Three Different Types of Vehicles



Dynamic Weight Transfer Effects -- The effect of dynamic weight transfer is shown in Figure 27. Here a moderately "hard" 0.5 g deceleration stop by empty vehicles is compared to the static (zero deceleration) condition. It can be seen from this figure that the front axle of the car experiences a 17 percent increase in its portion of the load distribution under these conditions. Comparatively, the single-unit truck experiences an equivalent 51 percent increase while the combination-unit's tractor experiences a 35 percent front axle increase -- about the same level as the car.

Figure 27. Weight Distribution for Three Different Types of Vehicles (Empty) at Two Deceleration Rates



Wheel Lockup Effects -- Limit performance braking capability is greatly influenced by basic tire traction properties and the effect that lockup of the tire/wheel has on these properties. In turn, locked wheels affect both vehicle stability and control and stopping distance performance.

Figure 28 shows the longitudinal (braking) force and lateral (side) force of a tire as a function of percent rotational slip of the tire. Percent slip is a measure of how much the tire is slipping with respect to the road surface as the vehicle is moving on the road. A fully rolling tire has 0 percent slip and a fully locked tire (wheel stopped completely) has 100 percent slip. It can be seen in Figure 28 that braking or longitudinal force is zero when the tire is rolling, reaches a peak at about 10-15 percent slip and then falls off to a somewhat lower level when the tire is fully locked. The shape of this curve is dependent upon the tire characteristics and the road surface properties. Typically, the peak is relatively high on dry roads but the fall-off is small. On wet roads the peak is lower and the fall-off as the wheel locks is much greater. The curve for side (lateral) force shows that this force is maximum when the tire is rolling but falls off rapidly as slip increases. It reaches essentially zero when the wheel is fully locked. This side force is critical to vehicle dynamics because it provides the force necessary for steering on front axle tires and provides yaw stability at all the other axles. Figure 28 clearly indicates that wheel lockup is undesirable. If it occurs, stopping distance performance will be reduced due to the fall-off in longitudinal force and/or stability and steering control will be lost due to the fact that lateral force essentially drops to zero.

Figure 28. Tire Traction Properties

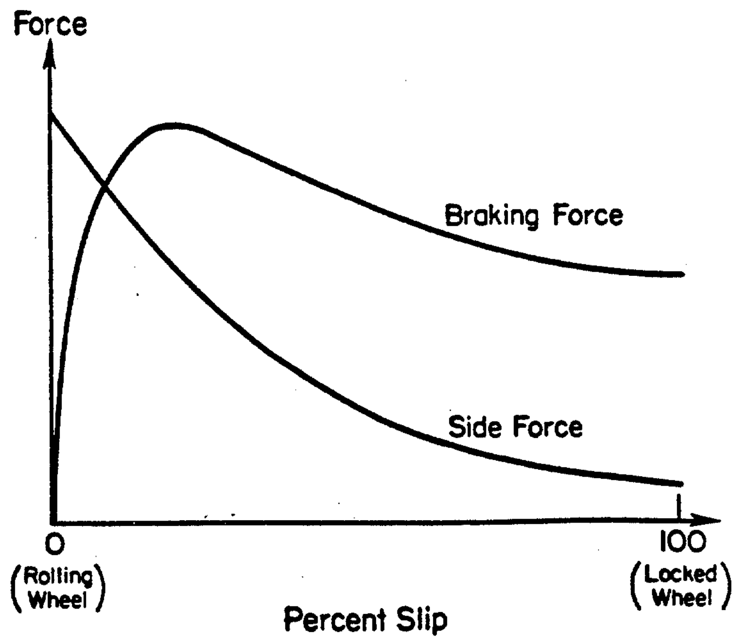
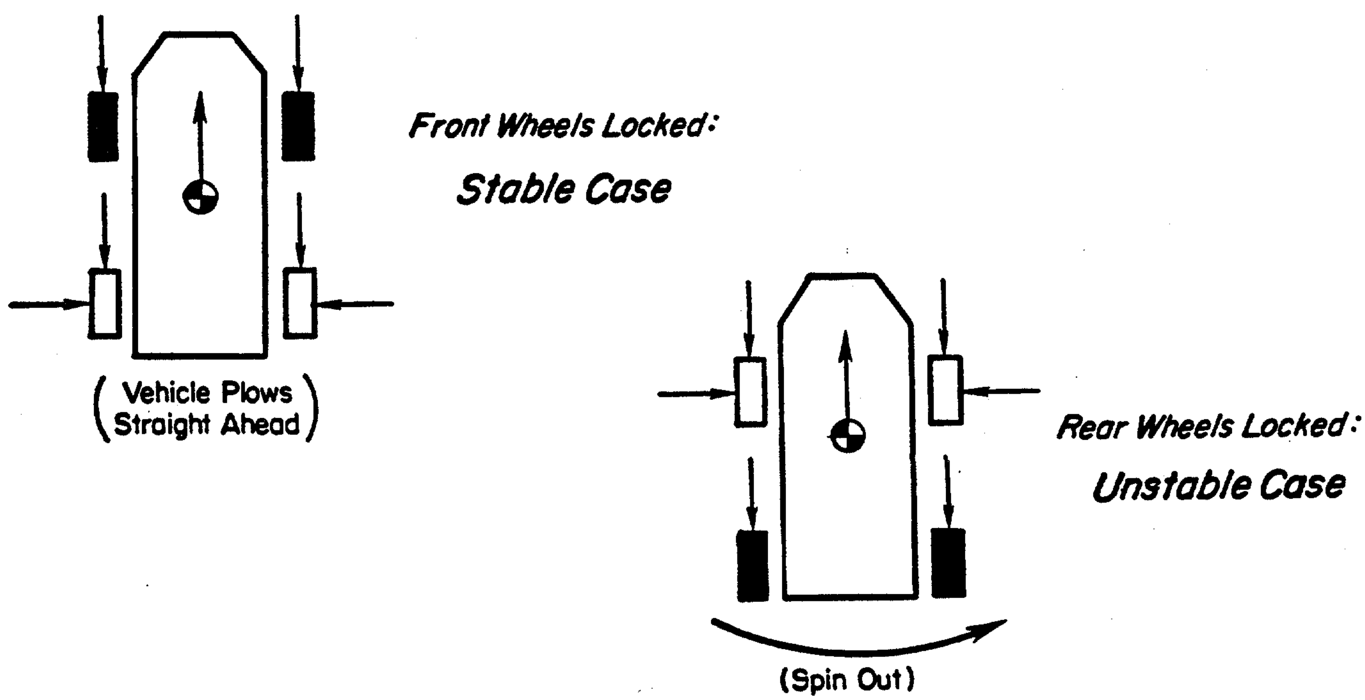


Figure 29 shows a simple two axle vehicle (car or single-unit truck) with only its rear wheels locked and only its front wheels locked.

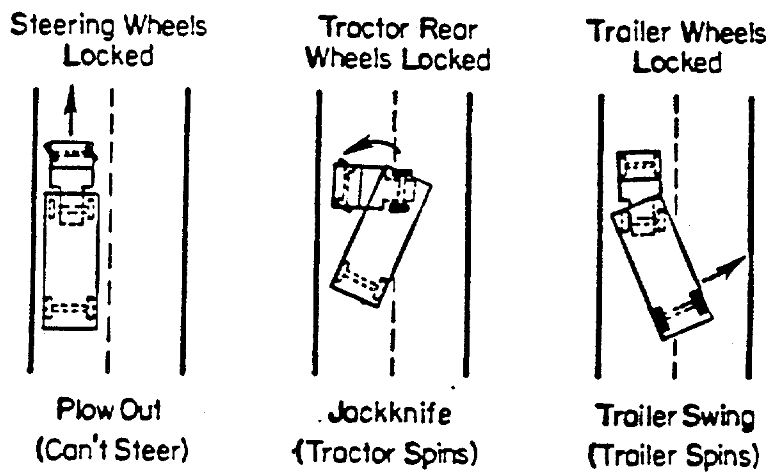
Figure 29. Vehicle Dynamics With Locked Wheels -- Simple Two Axle Vehicle



In the "rear wheel only" lockup case, the vehicle is very unstable and the slightest side force disturbance (lateral force due to turning, side slope or road crown, crosswind, etc.) will result in the vehicle spinning or yawing uncontrollably. With the front wheels only locked and the rear wheels rolling, the vehicle cannot be steered but is stable and does not tend to spin or yaw. If all wheels are locked, the vehicle cannot be steered but is still relatively stable, not unlike the front only locked case.

When we look at combination-unit vehicles, the effect of wheel lockup can easily be inferred from the simple single-unit vehicle case each vehicle in the combination is treated as a single-unit vehicle. Figure 30 shows a tractor trailer with fronts only locked, tractor rears only locked and trailer only locked.

Figure 30. Tractor Trailer Dynamics With Locked Wheels

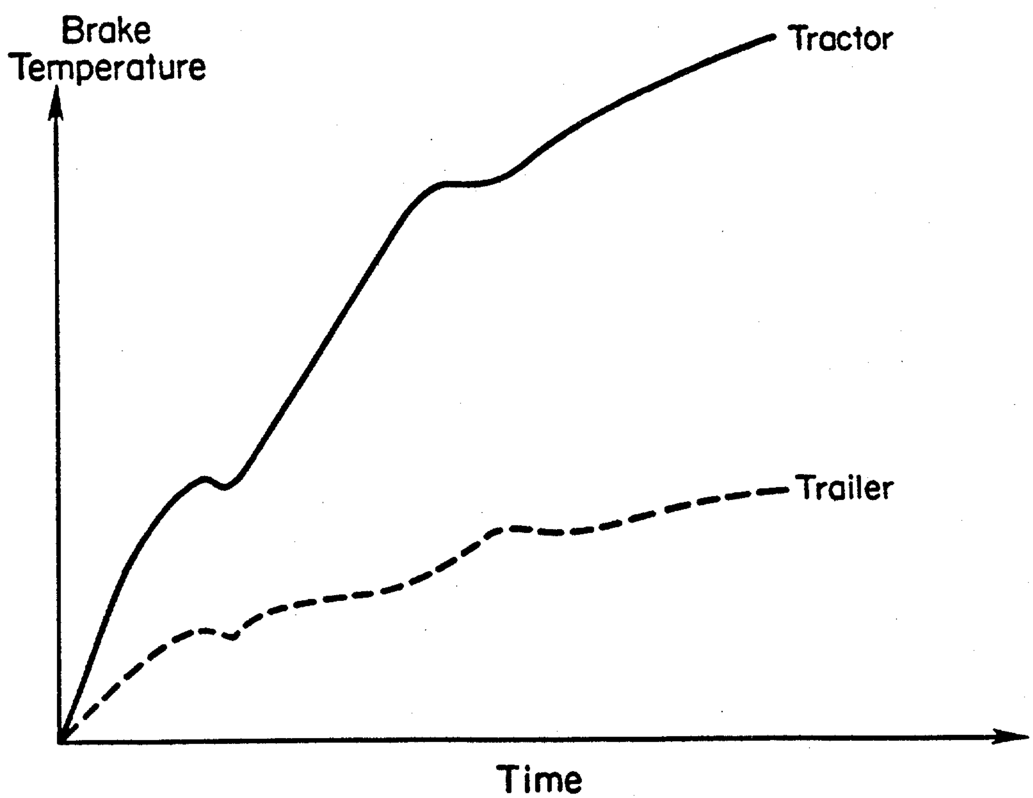


In the front wheels locked only case, the tractor, although it can not be steered, is stable and does not spin. The trailer follows along behind it in a straight ahead fashion. When the tractor rear wheels lock, the tractor wants to spin out but is constrained to pivot about the tractor to trailer coupling point. It spins rapidly into the trailer and jackknife occurs. With the trailer wheels locked, the trailer wants to spin about the coupling point. Although the trailer can swing into the tractor producing the same end result as the jackknife case, trailer spin or "swing" occurs much more slowly than tractor spin due to the fact that the trailer has much greater rotational inertia (primarily due to its length). Because trailer swing occurs much more slowly than the classic tractor jackknife, it is potentially easier for the driver to control this loss of stability situation since he has more time to react and take corrective action.

Braking Compatibility Between Tractors and Trailers

Brake Force -- Braking force balance between tractor and trailer(s) in combination-unit vehicles can play a significant role in the ability of a vehicle to safely descend a grade. Figure 31 shows a hypothetical example of a combination-unit vehicle where the braking forces on the tractor and trailer are not distributed evenly.

Figure 31. Brake Temperatures During Grade Descent -- Hypothetical Example of Tractor and Trailer that are Not Compatible.

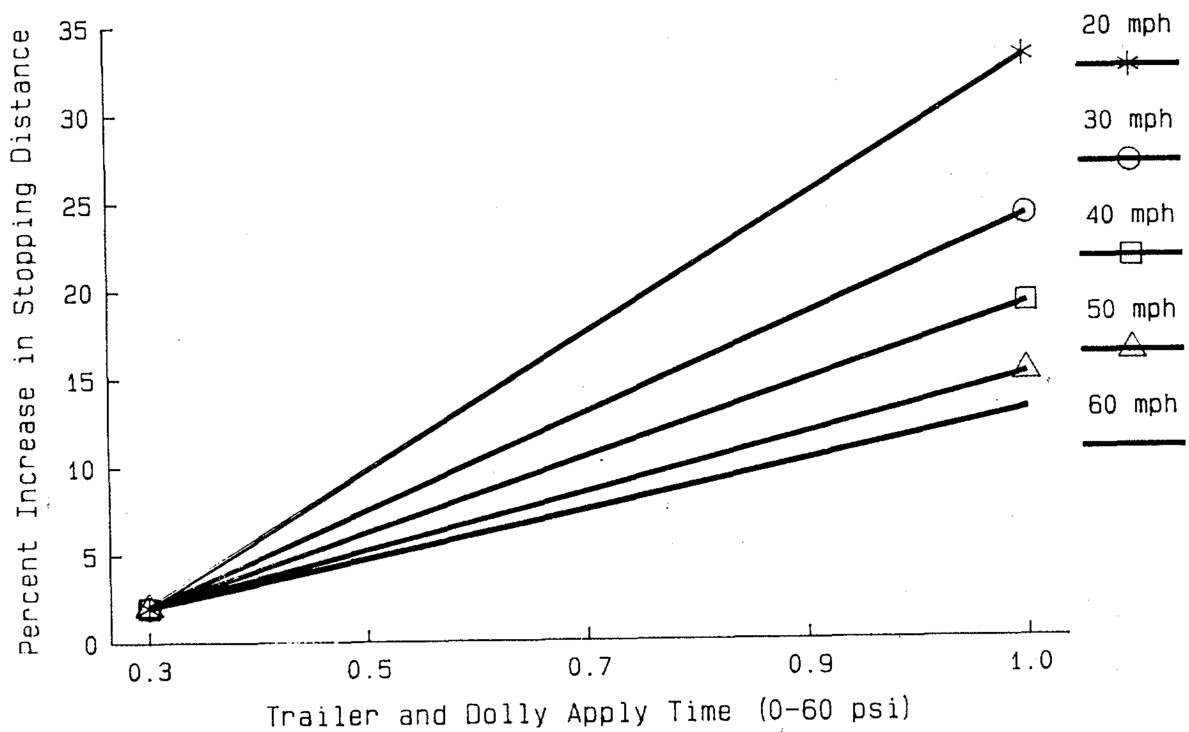


In this example, the trailer's brakes, because they are not doing enough braking, run at a relatively low temperature. The tractor, on the other hand, because it is doing too much work, runs relatively hot. It is possible in such a case for the tractor brakes to reach such a high temperature that they fade (lose effectiveness), begin to disintegrate or even catch fire. Since most grade descents are made at comparatively low brake application pressures, balanced braking at low pressures is critical.

Pneumatic Timing -- In addition to balancing braking forces between tractors and trailers, it is important to have the brakes on the trailer apply as quickly as possible with respect to the tractor. Large differences in the time it takes to apply the trailer's brakes compared to those on the tractor creates the effect of the trailer "bumping" or extra pushing force on the tractor in a "hard" stop. Although testing indicates this extra "pushing" has only a small effect on vehicle stability, drivers find it disconcerting , making some reluctant to attempt "hard" stops.

It is also important to have brake application and release times be as quick as possible, from an absolute viewpoint. This may be difficult on the trailing axles of long combination-unit vehicles. NHTSA testing has found that apply times can exceed 1 second and release can exceed 2 seconds on some combinations. Figure 32 shows the effect of trailer and dolly apply timing in a typical doubles combination on vehicle stopping distance from various speeds. The reference level in this figure is 0.3 sec, the apply time for a typical single-unit vehicle.

Figure 32. Effect of Trailer and Dolly Apply Timing on Vehicle Stopping Distance



SOURCE: NHTSA/VRTC Tests

Although long release times do not affect stopping distance, they do make it difficult for a driver to release the vehicle's brakes quickly in the event that he overbrakes and locks his wheels. If he keeps his trailer wheels locked for any appreciable length of time, trailer swing and/or dolly jackknife can occur.

Although it is difficult, if not impossible, to achieve trailer and dolly apply and release times that approach the single-unit vehicle level, the use of control line booster/quick release valves in long combination-unit vehicles greatly improves performance by minimizing apply and release timing. Unfortunately these booster/quick release valves are not used universally.

Purchase Specification Factors -- Automatic Limiting Valves

Brake application pressure to the front axles of many combination-unit trucks is mechanically reduced with a device called an automatic brake pressure limiting valve (ALV). Many truck purchasers specify these valves when they purchase new trucks and tractors. They are optional equipment on most trucks, but standard on some. These valves are popular because drivers are fearful of losing control of their truck during braking. They perceive this occurs because front wheel brakes are too powerful and that as a result, the front axle will lock or the vehicle will pull to one side during a "hard" brake application. Steering wheel pull during braking can be caused by a number of factors, most of which relate to poor front brake maintenance. The result is that front axle braking forces become unbalanced left to right. Unbalanced braking forces can be caused by unequal brake adjustment on the front axle brakes, grease on the brake linings, or a non-functioning or improperly operating brake. Because of the geometry of most truck steering systems, when these unbalanced braking forces occur, they are transmitted to the steering wheel in the form of a pull on the rim. The bigger the front brakes, the greater the magnitude of the pull felt by the driver. The pull force level can be substantial with manual steering, but is greatly reduced with power steering.

Automatic limiting valves are prevalent among combination-unit truck tractors. Interestingly, power steering is even more prevalent (see Table 32). These trends are especially prevalent among late model vehicles (see Table 33). This is a seeming contradiction, since power steering counteracts the effects of "pull", the major reason the ALV's are there in the first place.

In some cases, the use of ALV's can compromise the safety performance of a vehicle. First, ALV's effectively cover up front brake maintenance problems. In a panic or limit performance braking situation, any braking imbalance, which was present, but which the driver did not feel during "normal" braking, could result in a significant steering wheel pull that he is not prepared to handle (due to the element of surprise). Secondly, they have a negative impact on limit performance stopping capability when the vehicle is operating empty or on slippery roadways. Table 34 shows the stable stopping performance of different vehicles measured in tests at VRTC under various braking conditions.

Table 32. Prevalence of Automatic Front Wheel Brake Pressure Limiting Valve and Power Steering Among U.S. Combination-Unit Trucks

Location of Sample	ALV's	Power Steering	Total Vehicles Sampled
Texas	216 (24.7%)	652 (74.7%)	873
California	287 (56.8%)	296 (58.6%)	505
Maryland	446 (47.7%)	607 (65.9%)	934
Total	949 (41.0%)	1555 (67.3%)	2312

SOURCE: Kirkpatrick (1986) and Smith (1986) Cunagin (1986)

Table 33. Prevalence of Automatic Front Wheel Brake Pressure Limiting Valves and Power Steering on U.S. Combination-Unit Trucks by Model Year

Model Year	ALV's	Power Steering	Total Vehicle Sample
< 65	2	1	8
66 - 70	4 (11.1%)	8 (22.2%)	36
71 - 75	31 (17.7%)	50 (28.6%)	175
76 - 80	241 (45.2%)	287 (53.8%)	533
81 - 86	455 (66.2%)	557 (81.1%)	687
Total	733 (47.7%	903 (65.0%)	1439

SOURCE: Kirkpatrick (1986) and Smith (1986)

In all of the test cases, performance is improved by removing the ALV. The braking-in-a-curve maneuvers are included because proponents of ALV's state that they are of a particular advantage in controlling the vehicle while braking and turning because they eliminate the possibility of steering axle lockup and loss of steering control. The test data indicate that with or without the ALV, it is not steering axle lockup that limits performance, but drive or trailer axle lockup. With the ALV installed, lockup of the drive and/or trailer axles is more premature (i.e., at a lower deceleration) and the chance of jackknife or trailer swing is greater. Test results were basically the same, using either skilled test drivers, or actual over-the-road truck drivers.

Finally, ALV's can also create problems, or at least worsen them, in downhill braking situations. Since grade descents are typically made using low brake application pressures, the front brakes do little work on an ALV equipped vehicle. This places greater demand on the other brakes on the vehicle, some of which may not be in adjustment or fully operative, and are, therefore, unable to assume the thermal load. As a result, overheating and brake fade probabilities are increased.

Table 34. Stable Stopping Performance (ft) With and Without Automatic Front Axle Brake Pressure Limiting Valves (ALV's)

Vehicle	With ALV	Without ALV	Percent Improvement
60 mph/Empty/Straight Line Stops			
6x4 Truck	440	355	20.0
6x2 Bobtail	418	324	22.5
50 mph/Empty/500 ft Radius Curve/Wet Asphalt			
6x4 Truck	268	233	13.1
4x2 Tractor/1-Axle Trailer	260	224	13.8
4x2 Bobtail	308	249	19.1
Auto Transporter (Stinger)	215	181	15.8
18 mph Loaded 500 ft Radius Ice Curve:			
6x4 Tractor/2-Axle Trailer	273	253	7.3%
4x2 Tractor/1-Axle Trailer	213	179	16.0%

SOURCE: NHTSA/VRTC Tests

Maintenance -- Brake Operation and Adjustment

Heavy truck braking performance, both limit performance stopping capability and routine speed control on downgrades, is tremendously affected by the maintenance condition of the braking system. It is obvious that if parts of the system are inoperative or not functioning properly, system performance deteriorates.

Heavy truck roadside inspections have, for years, routinely noted brakes as the vehicle component most often found deficient or inoperative and the principal reason for vehicles being placed out-of-service as imminently hazardous. This is highlighted by the data previously shown in Table 24.

Recent studies, focusing only on front steering axle brakes, indicate that this portion of the system is not maintained well. The data in Table 35 indicate that only half of the vehicles randomly surveyed had operative front wheel brakes. Of those that were inoperative, most had missing parts or were so out of adjustment as to render the brakes non-functional.

Table 35. Front Axle Brake System Condition of In-Service Combination-Unit Trucks

Condition	Location			
	Maryland	California	Texas	Total
Working	400 [40.6%]	352 [69.7%]	476 [54.5%]	1228 [52.0%]
Not Working*	584 [59.4%]	153 [30.3%]	397 [45.5%]	1134 [48.0%]
No Brakes	128 [13.0%]	96 [19.0%]	89 [10.2%]	313 [13.3%]
Missing Parts	108 [11.0%]	10 [2.0%]	119 [13.6%]	237 [10.0%]
Incorrect Adjustment	422 [42.9%]	53 [10.5%]	189 [26.1%]	664 [28.1%]
Total	984	505	873	2362

SOURCES: Kirkpatrick (1986), Smith (1986), Cunagin (1986)
* Subcategories of non-working brakes are not always additive. A vehicle may have had more than one deficiency

For the same reasons that ALV's are popular with drivers, many truck operators go a step farther and intentionally render front wheel brake systems inoperative on 3-axle trucks/tractors by disabling or disconnecting them or "backing-off" the adjustment to the point that the lining no longer contacts the drum. The Federal Motor Carrier Safety Regulations (FMCSR) have been revised to ensure that all trucks originally designed to have front wheel brakes (required by NHTSA for new trucks since 1980) in fact have them and that they are operational.

Table 36 shows the percent increase in stable stopping distance that occurs when the front brakes are disconnected. The test conditions considered were: 1) 60 mph straight line stop on dry road and 2) 18 mph stop on a 500 ft radius ice curve. The ice curve is included because proponents of disconnecting front brakes claim that this provides better steering control of the vehicle in braking and turning maneuvers on slippery surfaces.

It can be seen in Table 36 that in all cases removal of the front brakes degrades stable stopping performance. There are two cases (i.e., 6x4 empty truck on the dry road and 6x4 loaded tractor/tandem axle trailer on the ice curve) where the difference is small. However, both of these vehicles were equipped with automatic front axle limiting valves so that effectively, even when their front brakes were operational, they exhibited a relatively low level of front brake torque.

Table 36. Effect of Removing or Disconnecting Front Brakes on Stable Stopping Performance

Vehicle	Loading	Percent Increase in Stopping Distance w/o Front Brakes (%)
60 mph/Straight Line/Dry		
6x4 Truck #1	Loaded	26
	Empty	4
6x4 Truck #2	Loaded	31
	Empty	18
6x4 Tractor #3/Tandem Axle Trailer	Loaded	24
6x4 Tractor #3	Bobtail	19
6x4 Tractor #4/Tandem Axle Trailer	Loaded	19
6x4 Tractor #4	Bobtail	23
18 mph/500 ft Radius/Ice		
6x4 Truck #1	Loaded	21
6x4 Tractor #3/Tandem Axle Trailer	Loaded	11
6x4 Tractor #4/Tandem Axle Trailer	Loaded	2

SOURCE: NHTSA/VRTC Tests

In all cases, removal of the front brakes resulted in the drive or trailer axles locking up more prematurely (i.e., at a lower deceleration level). Thus, they would be more likely to spin out, jackknife or experience trailer swing in an emergency situation with their front brakes disconnected. This result tends to refute the main reason truckers give for disconnecting brakes -- that it helps them maintain vehicle control in emergency stops.

Brake maladjustment is a far more prevalent problem than totally disconnected front brakes. The front brake survey results shown in Table 35 indicated that 58.6 percent (664/1134) of the trucks with non-functional front brakes were in that condition because their brakes were totally out of adjustment.

Other surveys of brake adjustment have also indicated that the truck brake adjustment is generally poor. For example, Hargadine and Klein analyzed data in three states collected by BMCS in 1983. A total of 390 air braked vehicles were inspected and brake adjustment was measured.

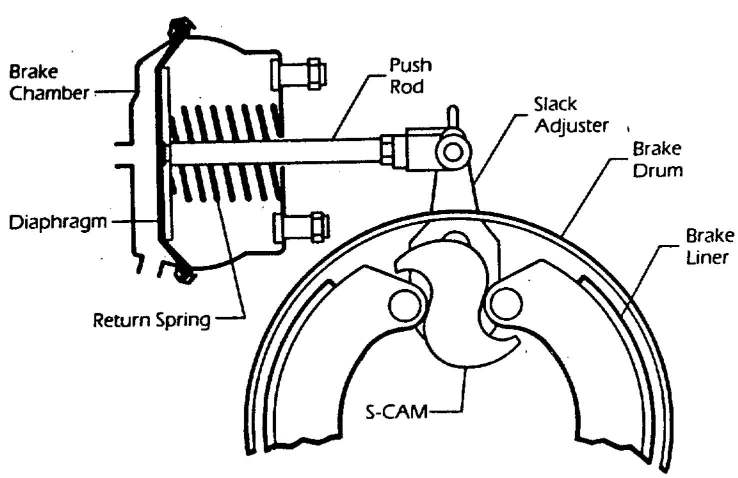
They found that the average truck had 30 percent of its brakes out of adjustment. The most recent study results (Table 35), when compared to those of Haradine and Klein, indicate that brake maintenance may actually be getting worse with time.

The torque output of air braked heavy trucks is very sensitive to brake adjustment level. This is not the case for hydraulic brakes used on heavy trucks (or cars for that matter) and, in any event, most hydraulic brakes on cars and trucks are of the automatic adjusting type. The majority* of truck air brake systems must be manually adjusted and thus their sensitivity to adjustment has a significant impact on in-use performance. Figure 33 shows a typical truck foundation brake assembly. As the brake lining wears, push rod travel must be adjusted at the slack adjuster to ensure lining contact with the drum.

Figure 34 shows the effect of brake adjustment on the output of a typical heavy duty air brake at two different temperature levels, 200°F and 600°F (temperature in the brake drum).

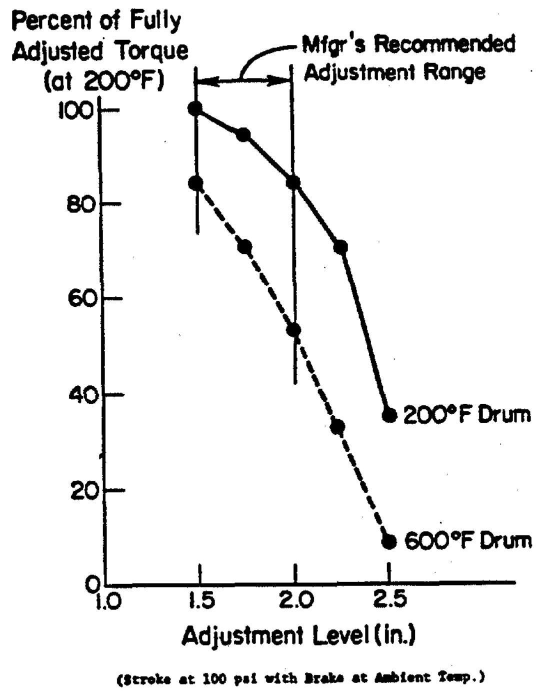
The lower temperature represents a relatively "cool" brake that has not been exposed to a great deal of repeated or continuous braking. The higher temperature represents a relatively "hot" brake, and is typical for a mountain descent although it is by no means the maximum temperature that a brake might experience in service. Figure 33 is for an S-cam drum type brake, used on the majority (over 90%) of heavy duty air braked vehicles.

Figure 33. Typical Truck Foundation Brake Assembly



* Automatic adjusters are available for air brakes and it is estimated that approximately 20% of the vehicles are now using them. Use of automatic slack adjusters is growing.

Figure 34. S-Cam Drum Brake Performance as a Function of Adjustment Level and Drum Temperature



SOURCE: NHTSA/VRTC Tests

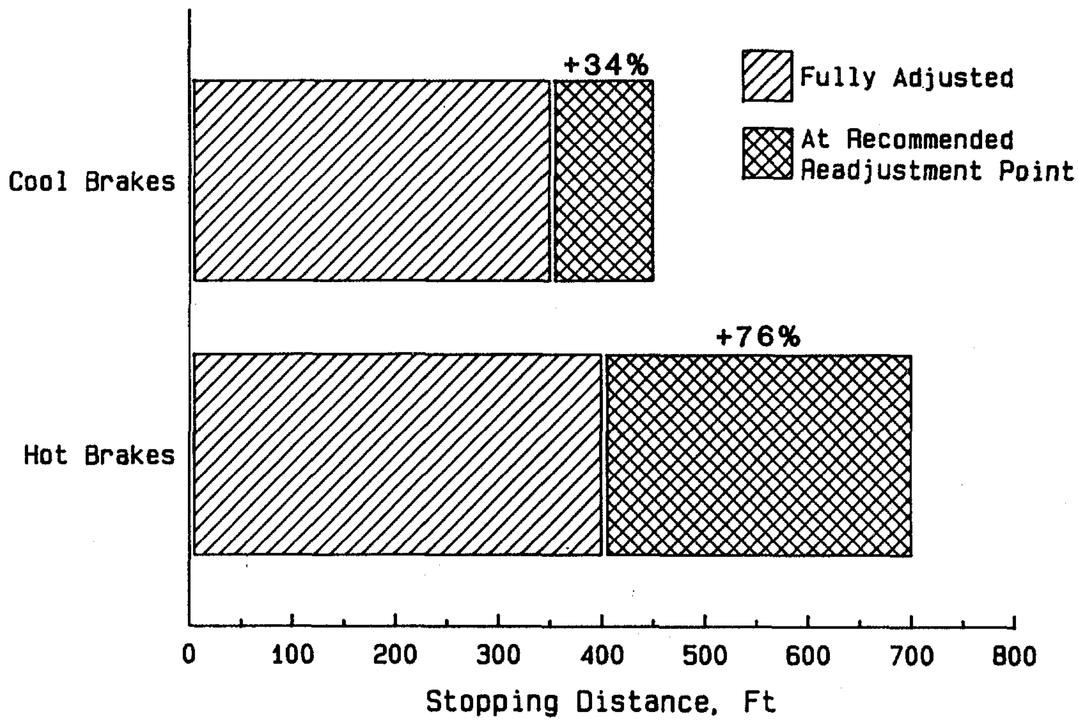
Adjustment level in Figure 33 represents the stroke of the air brake actuator (commonly known as the brake chamber) when the pressure in the actuator is 100 psi and the brake is at ambient temperature. Normally, for the brake shown, the stroke of the actuator at 100 psi with the brake fully adjusted is approximately 1.5 inches; this stroke is required to take up the slack and deflection in the system. As the brake shoe wears, the stroke increases due to the greater actuator travel necessary to move the brake shoes out against the brake drum. For this particular brake, the manufacturer recommends that the brake be readjusted when the stroke reaches 2.0 inches although the actuator actually has a full travel of approximately 2.5 inches.

It can be seen from Figure 34 that at 200°F brake temperature brake torque continually drops as adjustment level degrades from the fully adjusted level. This is true even over the manufacturer's recommended adjustment range; at the recommended readjustment point (2.0 inches of stroke) the torque has dropped to 85 percent of its fully adjusted level. When the brake is hot (600°F), there is a drop to 85 percent even when the brake is fully adjusted. This drop is due to two factors: 1) brake lining fade at the elevated temperature brake and, 2) drum expansion which results in an actuator stroke increase. Brake torque is reduced 50 percent compared to a fully adjusted level cool brake, when adjustment reaches the manufacturer's recommended readjustment point. This is a significant drop even though brake adjustment is considered to be acceptable in terms of the manufacturer's recommendations. Under this condition, the brake can only develop one half of the torque it could if it was fully adjusted and cool. Beyond the manufacturer's recommended adjustment range brake torque drop is even more dramatic, particularly if the brake is hot.

Reduced brake torque due to brakes being out-of-adjustment affects the brake force balance and overall thermal capacity of the vehicle. As a result, not only is limit performance stopping ability affected, but downhill operations also become more prone to brake fade and runaway.

Figure 35 shows the results of limit performance stopping distance tests conducted on a fully loaded 6x4 truck at two different adjustment levels: 1) fully adjusted, and 2) at the manufacturers recommended readjustment point. Beyond the manufacturer's recommended adjustment range the stopping distance of the vehicle would be even longer than that shown in Figure 35.

Figure 35. Stopping Distance of Fully Loaded Truck at Two Brake Adjustment Levels (60 mph -- Dry Road)



SOURCE: NHTSA/VRTC Tests

Brake adjustment primarily affects the stopping capability of trucks when they are loaded, since this is where maximum brake torque is needed to decelerate vehicle mass. With an empty vehicle, more than enough brake torque is usually available to lock the wheels despite the level of adjustment, unless adjustment is so poor that practically no torque is generated.

Maintenance Factors -- Replacement Brake Linings

Brake linings are one of the two friction elements (the brake drum is the other) in the brake that generate the friction force that ultimately is translated into brake torque and braking force at the tire/road interface. Thus, the performance of brake linings obviously influences overall vehicle braking performance. Although FMVSS No. 121 specifies minimum overall performance requirements for brakes on newly manufactured trucks, it not does contain detailed torque generating performance standards for linings. Also, there are no regulations for replacement linings. Several States have placed requirements on replacement linings; however, it is a generally recognized fact within the industry that these do not ensure predictable performance on the vehicle, in spite of the fact that these State requirements specify performance on a laboratory test machine.

The Society of Automotive Engineers (SAE) is currently developing an improved method of rating brake linings. However, it appears it will be a long time before this effort is completed and even then it is not clear how comprehensive this rating scheme will be. In the meantime, heavy truck operators are faced with the problem of not being able to obtain linings which match the performance of those that came as original equipment on the vehicle.

The problem is twofold. First, identifying linings is a difficult task. Although most linings are edge-marked with a code (required by many States), these codes are very difficult to read and confusing to interpret. In addition, as the lining wears out, the code is destroyed, making it impossible to determine which replacement lining to use. Secondly, the performance of brake linings is known to vary widely from manufacturer to manufacturer, from formulation to formulation supplied by a single manufacturer, and even within a given formulation, from batch to batch.

The data contained in Table 37 illustrates this point. It shows actual on-vehicle measured differences in braking torque with two different sets of brake linings taken out of the same batch of product from two different lining manufacturers. At the higher brake pressure application levels (where limit performance stops are made), the differences become substantial and could, by themselves, contribute greatly to brake force imbalance.

Table 37. Differences In Measured Braking Force Between Two Sets of "Identical" Brake Linings of The Same Manufacturer

Brake Application	Difference in Brake Torque	
Pressure (PSI)	Brand A	Brand B
20	4%	19%
40	27%	33%

SOURCE: NHTSA/VRTC Tests

Given this amount of variation, it is difficult to achieve braking force balance particularly between tractors and trailers. Units are typically serviced at different times, by different personnel and in some cases even by different maintenance facilities. Brake linings that have low levels of effectiveness when cold or hot reduce the braking capacity of the vehicle to the point that it cannot safely stop the vehicle when fully loaded. Brake linings that have unusually high or low levels of effectiveness can create brake force imbalances which in turn cause wheel lockup and loss of stability. Mixing different performing linings on tractors and trailers can also result in temperature imbalances when descending grades (one vehicle will do more than its fair share of the work).

Maintenance Factors -- Brake Valves

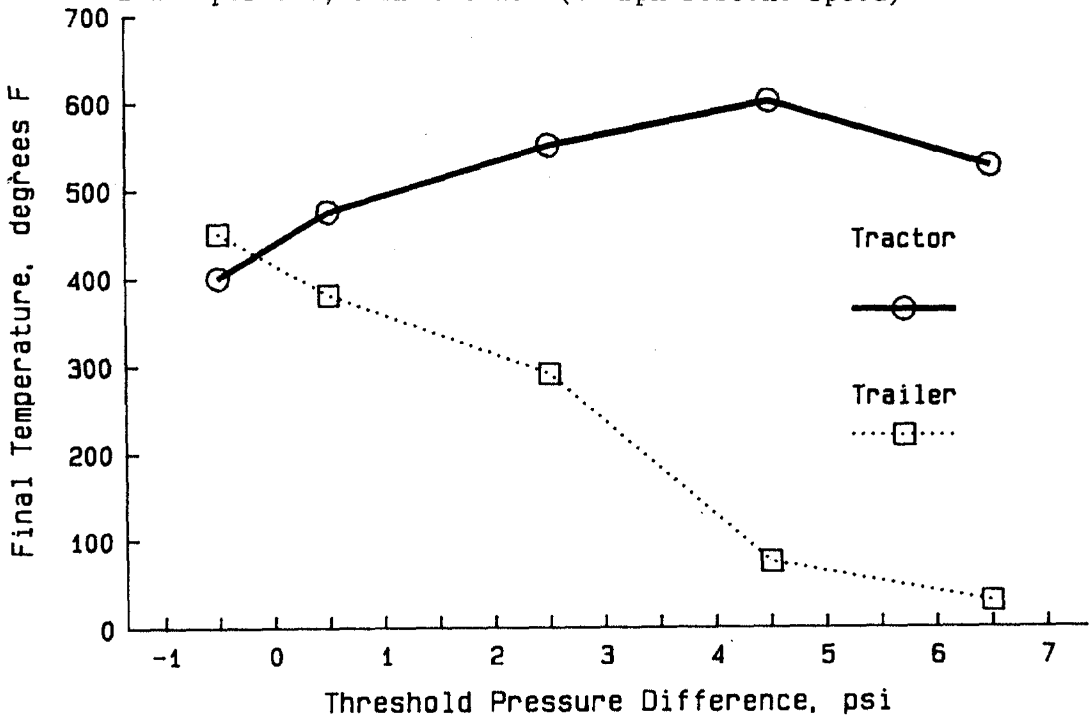
In the previous discussion on tractor trailer compatibility, the importance of having all the truck's brakes "come-on" equally and as close to each other in time was stressed. The brake application pressure at which the brakes "come-on" and braking torque actually begins to be generated is called the brake force threshold pressure or simply threshold pressure. If the threshold pressure on the tractor and trailer are not the same, downhill braking performance can be affected. One of the primary determinates of threshold pressures are the pneumatic valves used in air brake systems. There are many in a truck brake system. These valves take a finite pressure (called the "crack" pressure) to open due to internal friction and return springs in the valve. Differences in "crack" pressures exist.

NHTSA has performed tests to determine how differences in threshold pressure affects tractor and trailer brake temperature balance. Figure 36 shows the results of such a test.

Final brake temperatures (average of all wheels) on the tractor and trailer at the end of a 4 percent, 5 mile grade descent at 45 mph are shown as a function of difference in threshold pressures between tractor and trailer. In this test, a constant drag type of brake application was used. If the repeated snub approach had been used, the tractor and trailer temperature differences would have been significantly less due to the fact that repeated snubs are usually made at higher brake application pressures (this is one factor in favor of using the snub method for descending a grade). It can be seen from Figure 36 that temperature balance is very sensitive to small differences in tractor and trailer threshold pressures. In fact, only a 2 psi difference results in over a 200^{o}F temperature difference between the tractor and trailer.

Recent tests conducted on 15 combination-unit vehicles (9 tractor trailers and 5 doubles) in a relatively new condition give an indication of the range of threshold pressure differences that exist between tractors and trailers. Results of these measurements are shown in Table 38.

Figure 36. Effect of Difference in Threshold Pressure Between Tractor and Trailer on Brake Temperatures At the Bottom Of a 4 percent, 5 Mile Grade (45 mph Descent Speed)



SOURCE: NHTSA/VRTC Tests

Table 38. Brake Force Threshold Pressures for Tractors, Trailers, and Dollies

Vehicle Type	Threshold Pressure, psi
6x4 Tractors*	4.9 - 8.8
4x2 Tractors*	4.2 - 6.6
Tandem Axle Semitrailers	3.9 - 5.9
Single Axle Semitrailers	4.0 - 7.0
Single Axle Converter Dollies	3.3 - 8.8

SOURCE : NHTSA/VRTC

* Only brake force thresholds of the drive axles are shown since they provide the majority of the tractors braking. Steering axle brake thresholds covered a much broader range (4.5 - 15.0).

It can be seen from Table 38 that a tractor trailer combination consisting of the tractor and one or more of these trailers and converter dollies could easily have a threshold difference of more than two psi. For example, if the tandem axle trailer with the lowest threshold pressure (3.9 psi) was coupled to the 6x4 tractor with the highest threshold pressure (8.8 psi), a 5 psi threshold difference would result. Referring to Figure 36, such a combination would be expected to produce a staggering temperature imbalance in downhill operations.

There are no Federal Standards or industry design guidelines that address tractor/trailer threshold pressure. The Society of Automotive Engineers (SAE), however, is working on the development of a voluntary recommended practice at the present time.

Operational Use Factors -- Amount of Cargo

As noted in earlier discussions, it is necessary to size brakes for the fully loaded condition in order to provide enough overall braking force and reserve thermal capacity. This results in the vehicle being significantly "over braked" when it is lightly loaded or empty. Couple this with operation on a wet or slippery road, and all the conditions are present for a wheel lock-up induced loss-of-control accident should an accident-avoidance braking maneuver be attempted.

The data in Table 39 indicate that significant portions of many truck operations involve movements with lightly loaded or empty vehicles.

Table 39. Trucks Operating Lightly Loaded Or Empty, Five Axle Tractor Semitrailer Combinations

Trailer Body Type	Number Sampled	Percent Operating Lightly Loaded*	Percent Operating Empty
Van	54,529	21.5	19.0
Tanker	10,296	11.2	35.6
Flatbed	23,192	15.6	26.5
Dump	3,772	7.0	39.8
Livestock	1,332	11.0	22.2
Hopper	1,009	2.8	48.7
Auto Carrier	1,430	28.8	11.0
Not Determined	89,025	19.5	30.4
Others	4,042	8.5	36.3
Total Sample	192,327	18.6	27.0

SOURCE: FHWA Annual Truck Weight Survey, 1980-1984
*Lightly Loaded = 35,000-50,000 lbs GCW

Operational Use Factors -- Bobtail Movements

When a truck tractor is operated on the highway without a trailer, it is referred to as being in a "bobtail" operation. In this condition, the vehicle is extremely overbraked on the rear axles. Under normal loaded conditions, routine sublimit performance stops are typically made using brake application pressures in the 20 - 30 psi range. A "hard" limit performance stop typically involves 85 - 90 psi application pressures. The data in Table 40, based on NHTSA tests, illustrate the extremely low application pressure levels at which bobtail tractor drive axles will lock.

Table 40. Brake Application Pressures (in psi) Needed To Cause Bobtail Truck Tractor Rear Axle Wheel Lock-Up

Tractor Type	Road Surface	
	Dry	Wet
Two Axle Tractor	30	10
Three Axle Tractor	30	20

SOURCE: NHTSA/VRTC Tests

Since the vehicle has a comparatively short wheel base, the likelihood of a spinout (unstable yawing) and loss-of-control accident is greatly increased when rear wheel lock-up occurs with a bobtail tractor. Systems are available to automatically reapportion more braking force to the front axle when a tractor is operating bobtail, but they are not widely used. The parts for this system cost about $50.00.

Campbell and Carsten (1981) estimated that truck tractors are infrequently operated bobtail (less than 1 percent of truck tractor mileage). They noted, however, that injury and fatal accident involvement rates for bobtail tractors were significantly higher than when the vehicle was pulling a trailer (see Table 41).

Table 41. Accident Involvement Rates of Selected Combination-Unit Trucks

Vehicle Type	Severity of Accident	
	Fatal*	Injury Only*
Bobtail Truck Tractor	90.0	913.5
Truck Tractor/Semitrailer	6.5	47.9

SOURCE: Campbell and Carsten 1981
* Accident involvement rate per hundred million vehicle miles

Measured Braking Performance of Medium and Heavy Trucks

When gauging the in-use performance of heavy trucks relative to their braking capabilities, two aspects of performance must be considered: stopping distance and stability. Stopping distance tests can be conducted basically in two ways: 1) panic stops with no limit on wheel lockup, and 2) driver modulated stops up to the point of lockup. In the panic stops, the driver simply "slams-on" the pedal and holds that level until the vehicle stops. In a modulated stop, the driver applies the pedal up to a deceleration level just below the point at which wheel lockup* occurs and holds that level until the vehicle comes to a stop. The significant difference between these two types of stopping distance tests is that a panic stop does not take into consideration the stability and control of the vehicle during braking.

Controlled panic stops may be possible in a flat test track environment, and in fact may yield relatively short stopping distances. However, in real-world driving situations with curved or crowned roads, a locked-wheel stop frequently leads to a dangerous loss-of-control. In addition, a locked wheel panic stop is more a test of tire longitudinal traction capability than it is a braking test, although it does evaluate reaction time of the braking system and whether the brakes have sufficient torque to lock wheels. On the other hand, tests employing modulated stops to the point of wheel lock evaluate the stopping capability of the vehicle while under full directional control of the driver. A modulated stopping distance test provides a much better measure of overall braking force balance and braking efficiency.

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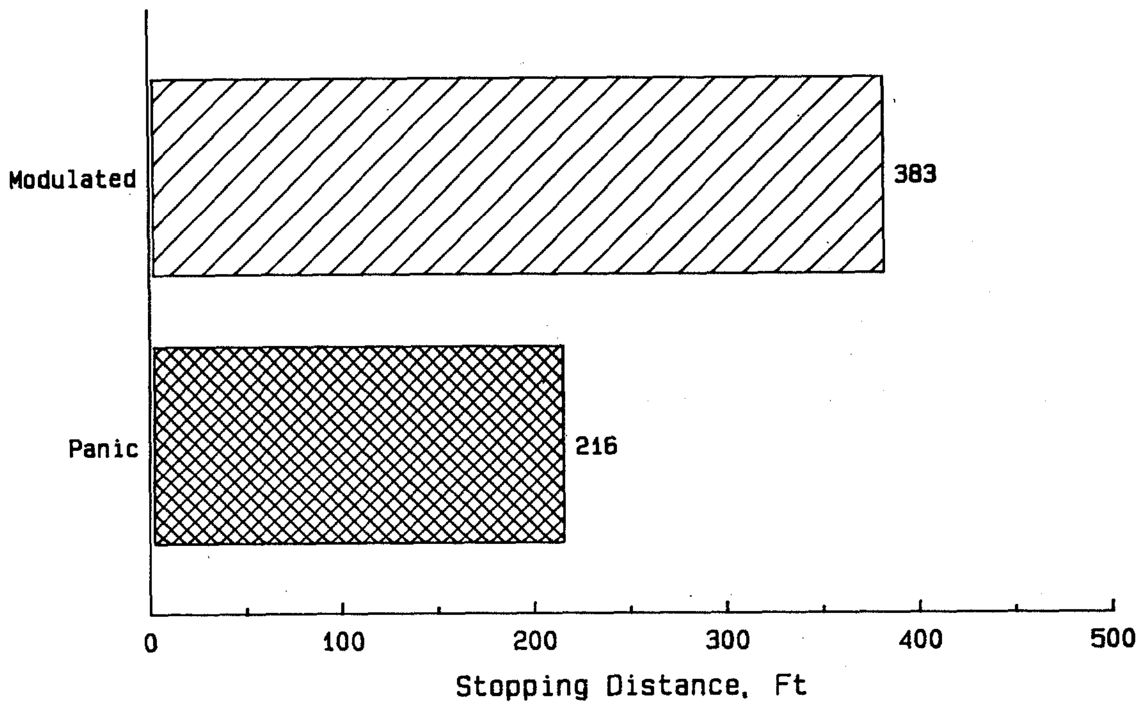
*In tests conducted by NHTSA, some limited lockup was actually permitted to occur. One wheel per axle was allowed to lock. This permits some left to right unbalance in either braking or loading to exist. Since at least one wheel on an axle was always rolling, stability was maintained.

It should be noted that the difference in stopping distance (or deceleration) measured using the two different approaches can be significant. In most cases involving trucks, panic stopping distances will be significantly shorter. Notwithstanding, this is not a good measure of how well the truck can be stopped since loss-of-control during one of these types of stopping maneuvers happens easily and frequently. For this reason, it is important to know what type of testing method was used when comparisons are being made about the relative stopping performance of different types of vehicles. Figure 37 demonstrates the difference in stopping distance that can occur, using the two approaches.

Figure 37. Stopping Distance From 60 mph on Dry Pavement For a 3 Axle Bobtail Tractor Using Two Types Of Testing Techniques

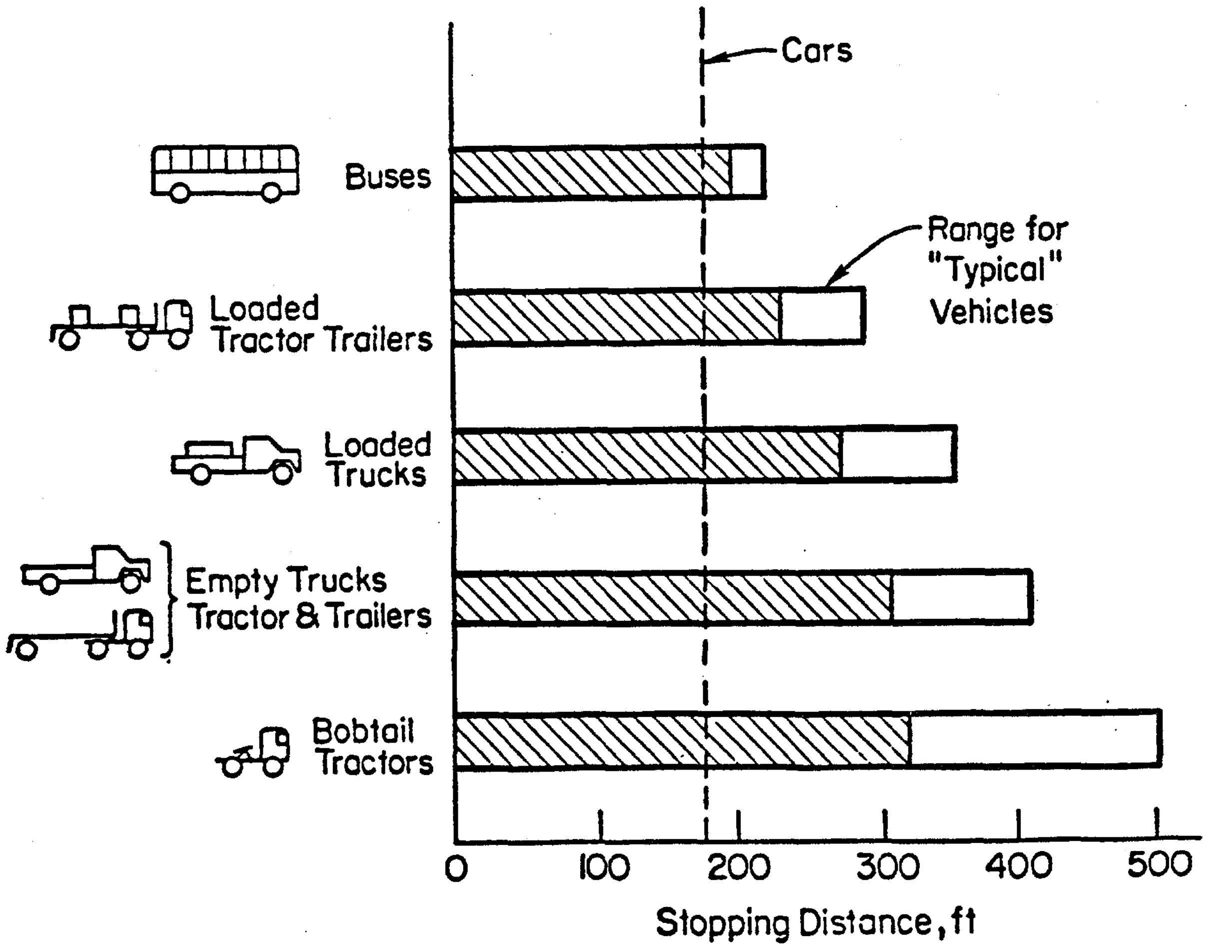


SOURCE: NHTSA/VRTC Tests

Stopping Distance Performance

Since panic stopping distance tests do not address the stability and control characteristics of vehicles during braking, all braking performance comparisons are best made using the modulated stop technique. Figure 38 shows the stable stopping distance from 60 mph on dry pavement for various types of air braked vehicles using this method. Also shown for reference is the stable stopping distance of a typical passenger car under similar conditions.

Figure 38. Stable Stopping Distance of Heavy Air Braked Vehicles From 60 mph on Dry Road



SOURCE: NHTSA/VRTC Tests

Figure 38 shows that buses (empty and loaded) perform relatively well. This is because they typically have a long wheelbase and relatively low center of gravity height resulting in minimal weight transfer during braking. Additionally, their empty versus loaded weight distribution is not significantly different. This makes it easy to achieve good brake balance over the range of operating conditions. Buses do take a little longer distance to stop than passenger cars primarily due to the lower traction performance typical of the heavy duty vehicle tires.

Loaded tractor trailers come next. Since their brake systems are optimized for the loaded condition they perform reasonably well. They do not do as well as buses because their steering (front) axle brakes are usually relatively small. Loaded trucks do not do as well as loaded tractor trailers because they experience more weight transfer onto the front axle but still have relatively small front brakes.

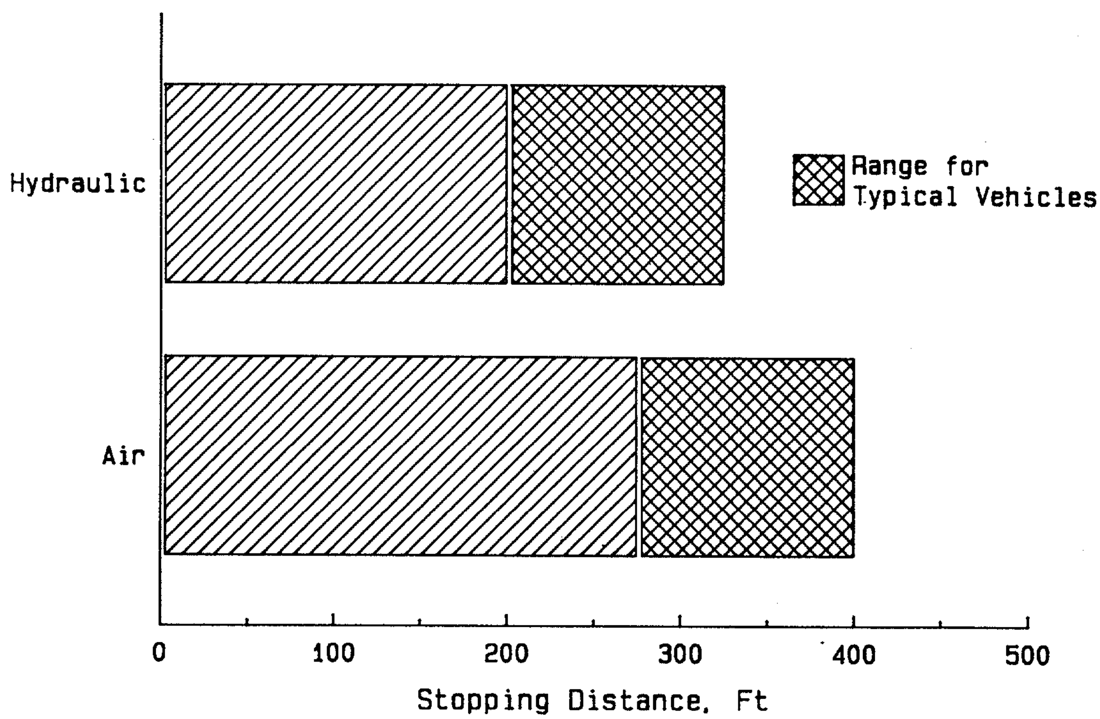
Performance of empty vehicles, particularly bobtail tractors, is relatively poor. It was found that very short (100 inches or less) wheelbase bobtails required as much as 500 ft to stop, this is almost three times as long as the typical passenger car.

Heavy hydraulically braked trucks were found to perform somewhat better than air braked trucks*.

Figure 39 shows the relative performance of typical trucks with air and hydraulic brakes. Performance of the hydraulically braked vehicles is better primarily because they are designed with higher torque front brakes and achieve better braking force distribution particularly when empty.

It should be pointed out that although the data in Figures 36-38 are based on dry pavement stops the relationships shown on these figures would hold for different surfaces as well. Stopping distances of all vehicles will increase, however, as the surface becomes more slippery.

Figure 39. Relative Performance of Trucks Equipped With Air and Hydraulic Brakes -- 60 mph, Dry Road



SOURCE: NHTSA/VRTC Tests

*Class 6 and 7 straight (single-unit) trucks and school buses are available from some manufacturers with either air or hydraulic brakes. Hydraulic brakes are standard on these vehicles and air brakes are offered as an option. Because of the additional complexity of the air brake system, the cost of such a system is higher.

Introduction

Truck brakes must provide speed control and short stable stopping capability under two distinctly different conditions. Over 90 percent of all stops made by medium/heavy trucks are routine (sublimit) in nature, i.e., stops requiring brake application pressures less than 30 psi. The remainder of the stops involve much higher brake application pressures (>85 psi) needed to perform an accident avoidance maneuver. This represents an extremely broad performance range. Efforts to optimize performance at one end of this range should not be done at the expense of performance at the other end. New systems that improve limit performance but which require much higher levels of maintenance to keep operational, which fail in unsafe modes, or which require special driver skills to successfully use, are not acceptable replacements for present systems -- despite their shortcomings. History has shown that new systems, if they have any of these attributes, create more problems than they attempt to solve. Added complexity, however, should not be used as an excuse for failing to improve performance. What is needed is a balance.

The ideal medium/heavy truck brake system would be designed so that each wheel of the single-unit truck or combination-unit vehicle would "know" the amount of brake force it must produce, under all conditions of vehicle loading and operation, and produce that amount of brake force. The system would automatically compensate for load condition, variations in tire size and tire/road conditions (varying levels of tire to pavement friction), etc. The system would be self-diagnosing, self-correcting (that is, would automatically adjust to compensate for the degradation of component performance as they wear in normal service), and utilize components labeled such that correct replacements could be made at times of maintenance and repair.

Maintenance costs would be a minimum. Reliability would be a must. The system must be fail safe. The system would be impervious to ice, water, road salts, oil, etc. The system would provide the driver with continuous information regarding the performance level of the brake system as well as indicate the need to perform maintenance and/or replace critical items due to wear or failure.

The brake system described above -- if it were reliable, easily maintainable, and reasonably priced -- would, in fact, result in vehicles which stopped in a controllable (stable) manner under all conditions of operation. As should be obvious from the discussions to this point, the current air-brake systems on U.S. vehicles do not meet many of these desirable goals.

In the early to mid-1970's, NHTSA, through the requirements of FMVSS 121, attempted to establish a set of performance requirements for medium/heavy vehicle air-brake systems. The standard established requirements for brake timing, emergency braking capability, fade and recovery, parking brakes, component/subsystem performance, and short stopping distances without wheel lockup. One of the impacts of this standard was a significant increase in air-brake system complexity -- a situation which proved to be troublesome to the industry mainly because they were not fully prepared to maintain the new technology. Also, the lack of reliability associated with the initial antilock systems was the principal reason that the stopping distance requirements, which necessitated the use of antilock brake systems, were struck down by the courts. Since that time, attempts have been made by both industry and government to identify and solve the various problems associated with U.S. air-brake systems, many of which surfaced as a result of having to deal with the original requirements of FMVSS 121 and the numerous modifications that have been made to the standard over the years.

The basic performance of medium/heavy truck air-brake systems was significantly upgraded as a result of the promulgation of FMVSS 121. For this reason, existing air-brake systems provide a good base from which improved performance can be obtained. The remainder of this section will focus on the steps needed to achieve this improvement.

Brake system components, especially those comprising the foundation brakes, have finite lives and must be periodically serviced and replaced. The initial objective of the overall program, therefore, is to achieve system designs which perform consistently and predictably until the time that they need to be replaced and that when replacements are made, to ensure that equivalent performance is maintained.

Brake systems today require far too much maintenance. Efforts undertaken to improve limit condition braking performance will be severely hampered unless a substantial effort is undertaken to design, develop, and install as standard equipment on all trucks a brake system that:

- Provides a positive and easily recognized way of replacing individual expendable components -- such as, brake linings, drums, valves, brake chambers, etc. -- with components having equivalent performance to that of the original equipment.
- Automatically stays in adjustment over the design life of the foundation brakes.
- Positively and automatically indicates when a component or subassembly has failed.
- Ensures that the braking system of a tractor manufactured by one firm when mated to a trailer built by another will function within acceptable ranges of performance, i.e., will be compatible.

Phase I of the Program

Current air-brake systems are deficient to some extent in all of these areas. These issues are the everyday "thorns in the sides" of conscientious motor carriers. Resolution of these problems will ensure that brake systems operate at the level of performance that was originally designed into the vehicle.

The industry will probably never have a single manufacturer making both the tractor and trailer. Fleets will always be interchanging different trailers among different tractors and mating new equipment (tractor or trailer) to older equipment. There will always be evolutionary change in various brake system components. Thus, compatibility will always be an important issue.

The agency views the major components of the brake system compatibility equation to be pneumatic timing and brake force balance. An NPRM has been issued to address the pneumatic timing issue. The Notice proposed changing the existing brake application and release timing requirements applicable to trucks, tractors and trailers, modifying the trailer test rig (mini-tractor) currently specified in the standard, and establishing new timing requirements for the control line coupling between towing and towed units. The proposed changes bring the timing requirements much closer to real world vehicles and should result in the most effective timing balance possible without increasing the complexity of the system.

The Notice prompted a series of industry-sponsored research tests which formed the basis for a substantive set of comments to the docket. Once the comments have been resolved, one half of the compatibility question will have been addressed.

The other half is the issue of brake force balance. The agency has carried out a number of tests in this regard and continues to work to provide data to the Truck Trailer Brake Research Group (TTBRG) and others describing the brake force versus control line pressure curve for optimum compatibility and to define an acceptable tolerance band for this curve. Final definition of this curve with appropriate tolerance limits will form the basis of a voluntary brake force compatibility standard.

Once a standard is written, the industry will need guidelines to ensure that compatibility is not degraded by changes made during routine maintenance. Examples would be using replacement valves and brake linings which perform differently from original equipment. Many valves appear on their exterior to be similar but in fact have greatly different performance characteristics. For example, crack pressures, which can greatly affect vehicle safety by upsetting the brake balance, can be very different among otherwise identical valves.

Brake lining performance is equally important. Absent new techniques for stopping vehicles, the friction of drum or rotor against a lining or pad will be the technique for stopping trucks in the foreseeable future. The present friction ratings used in the identification code are not good indicators of the compatibility of brake linings. Currently, the ratings are based on SAE J661a, a test procedure that is known to be unsatisfactory even for classifying the frictional characteristics of brake linings. The test does not give a measure which truly indicate how the linings will perform. For example, one vehicle manufacturer uses two brake linings interchangeably because they give equivalent performance, but, the linings have different SAE J661a identification code friction ratings. Also, by the time the lining has worn to the point where replacement is necessary, there are no identifying marks left on it to allow the consumer to select an appropriate replacement based upon the original lining. Something as fundamental as the lining should not be the relatively uncontrolled and unpredictable commodity it is.

Within the SAE, committees are currently working to develop voluntary standards or recommended practices to address both valve and lining performance. Although the actions of these committees are supported by the government and all segments of the trucking industry, the ATA, for one, would like to see regulations established for valve and brake lining performance. They are convinced that only in this way will uniformity be achieved. Precedents exist, since the agency already has regulations in place for certain other after-market products, e.g., brake hoses.

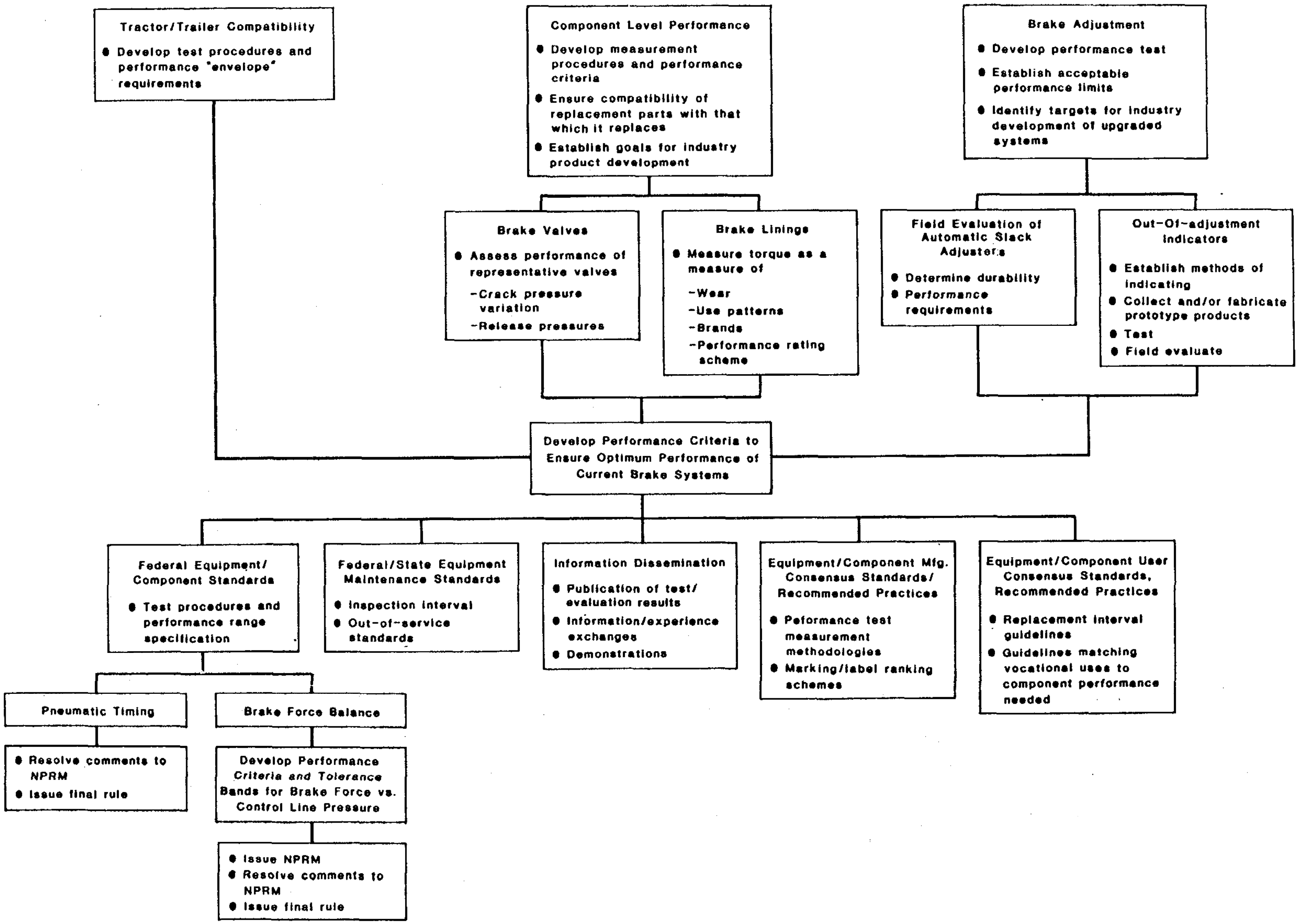
Brake adjustment is another critical issue which continues to demand attention. Agency performance data coupled with state acquired brake adjustment data defined the magnitude of the brake-out-of-adjustment problem among U.S trucks. A nearly completed field evaluation of automatic brake adjuster systems has provided mixed results. Although some currently available automatic brake adjuster designs do not appear to provide adequate performance, others were found to provide acceptable results. In any case, even the poorer performing automatic adjusters provide improvements relative to manual brake adjusters.

The results to date indicate two different needs. First, the manufacturers of automatic brake adjusters need, in some cases, to upgrade the performance of their products. Second, a performance test and acceptable performance limits need to be established. In addition, it is widely acknowledged that brake maintenance would be improved if brake adjustment indicators could be developed to provide motor carriers with information that brake adjustment is needed. Even with automatic brake adjuster systems, routine inspection and maintenance are still required. Development of such devices is an industry responsibility. The apparent strong need for these devices warrants sustained efforts by suppliers to develop durable products.

Finally, any devices and/or practices that result in a degradation of brake system performance should be prohibited. One example, is the removal of front axle brakes. The FMCSR are currently being modified to require that brakes be maintained and functional on all axles of in-use vehicles required by NHTSA to have brakes when the vehicle was newly manufactured.

The overall research plan which is needed to satisfactorily address many of these critically important near-term issues is diagrammatically shown in Figure 40. Resolution of these problems requires a commitment on the part of the truck manufacturers, component suppliers, drivers and motor carriers as well as the government. The government's role is to define performance requirements, including measurement methods and objective criteria, using existing consensus standards to the maximum extent possible. In addition, government can identify target goals for product development. The actual development of products needs to carried out by the industry. The government should also continue to evaluate in actual fleet service -- in cooperation with the industry -- the performance, reliability, maintainability, and costs of improved systems.

Figure 40.
Truck Brake Performance Improvement Program
Phase I



Phase II of the Program

Addressing the force imbalance and distribution problems arising from maintenance practices and/or widely variable component-level performance would provide reasonable, although not optimum, performance in normal braking situations. However, the system would still be deficient at limit conditions, i.e., when making a panic stop or when making a brake application that is too "hard" for conditions. Examples of the latter case would be when the driver has misjudged the amount of brake pressure he can safely apply when operating an empty or lightly loaded vehicle on a slippery roadway. The following Phase II program, which could be conducted concurrent with the Phase I effort, would address this issue.

U.S. designed heavy trucks employ fixed brake force distributions with a strong rearward bias. Also, brake capacity is sized to match the maximum fully loaded weight rating of each axle on the vehicle. Until a commitment is made to incorporate new brake system technology as standard equipment into new vehicles, there is no way that today's design can achieve force distribution and balance that is compatible with each of the wide variety of ways trucks can be loaded and/or operated. The problem becomes especially acute when the vehicle is empty.

The mismatched braking forces on a vehicle increases the likelihood of loss-of-control accidents (as wheels lock, single-unit trucks spin out, tractors jackknife, and trailers swing out of their lane) and downhill runaways, and worsens stopping distance performance. Short of the driver being extremely cautious when driving an empty truck, especially in inclement weather, the only currently available "fixes" appear to be load sensitive brake proportioning and/or antilock devices.

The simplest load proportioning device is one that senses whether the gladhands between tractor and trailer are connected. If the tractor is operating in the bobtail configuration, that is, without a trailer, the proportioning is readjusted such that more braking capacity is shifted from the drive axles to the steering axle. These devices, known as bobtail proportioning valves, have been shown to greatly enhance the stopping performance and stability of bobtail tractors. Reductions in 60 mph stable stopping distance from 500 ft to near 300 ft have been demonstrated with the addition of this relatively simple and inexpensive ($50) device. The accident discussed in Section 5 of this report is a typical bobtail tractor accident which would very likely have been prevented had the tractor been equipped with a bobtail proportioning valve. One domestic truck manufacturer offered such a system as a delete option several years ago, but made it an option in recent years because few purchasers were buying the system. The industry, however, is now becoming more aware of the value of the system. A second domestic manufacturer is beginning to provide these valves as standard equipment on certain models, and fleets are beginning to add these valves to their standard specifications when ordering new vehicles. Unfortunately, once a trailer is connected, the device cannot discriminate between a loaded and an empty trailer, and thus, provides no benefit in this case.

More sophisticated load proportioning devices are widely used on medium/heavy vehicles in Europe. In fact, the performance requirements of ECE Regulation No. 13 cannot be met without such a system. These devices continuously monitor the load on each axle by measuring the deflection of the suspension system. However, these devices have been found to suffer two problems which severely limit their applicability to present designs of U.S. vehicles. First, European vehicles typically have suspension travel ranges that are twice those found in U.S. vehicles. Also, fleet experience has shown that it is very difficult to keep the load proportioning system "calibrated" as a result of the hysteresis inherent in any spring system. The exposed linkage system used in these devices would also be very much subject to damage in U.S. operations. Therefore, application of such devices to U.S. vehicles would require the development of a different method for sensing load. The concept of load proportioning is much more attractive for vehicles which employ air suspension systems since the load is simple to sense and no hysteresis exists. In fact, one major domestic truck manufacturer -- because his predominate suspension is of the air variety -- is conducting research and development work on a load proportioning system for his products.

The second problem which has surfaced, especially in the United Kingdom, is the reliability of the system. Many systems have been disconnected by fleet operators because of sticking valves, contaminated air, and a myriad of other problems.

The final consideration, and maybe the most important, which limits the usefulness of sophisticated load proportioning concepts is the fact that they cannot provide protection against wheel lockup, nor compensate for torque variation due to maintenance and/or brake work history. Although the operating range of the driver should be expanded if his vehicle is equipped with a load proportioning system, he still would face the potential of becoming uncontrollable during accident avoidance maneuvers.

For these reasons, the most promising technology for significantly improving the braking performance of medium/heavy vehicles that is currently available is antilock brake systems. They are the only solution to the wheel lock and resultant controllability tendency typical with currently designed U.S. vehicles. Almost everyone in the trucking industry agrees that antilock has the potential to significantly improve the braking performance of heavy trucks by eliminating the directional instabilities which occur when wheels lock. Many, however, question the reliability and maintainability of the systems in actual use as well as the ability of the systems to fail safe (i.e., in the event of a malfunction the system reverts back to a normal brake system without antilock). Lack of reliability was the major reason for the Court's decision in 1978 to set aside the wheels unlocked stopping distances in FMVSS 121.

With the availability of second generation antilock systems, the recent advances in microprocessor technology, and greater acceptance of electronic controls on trucks in the U.S., it appears to be an opportune time to reconsider the issue of antilock use in this country. The agency is currently evaluating European antilock systems (at the present time there is no domestic production of antilock systems) on the test track.

In addition, these systems are being engineered into U.S. vehicles by at least one domestic manufacturer and fleets are purchasing antilock equipped single-unit trucks, tractors, and trailers for evaluation. Experience with the systems reported thus far has been very positive.

Despite the on-going and planned fleet evaluations, it is envisioned that a government-sponsored, longer term, more comprehensive, closely monitored fleet study, in cooperation with antilock suppliers, truck manufacturers, and motor carriers, will be necessary in order to acquire sufficient performance, reliability, maintainability, and cost data to support intelligent decision-making on the part of motor carriers and government. Since such a program would involve following 50-200 antilock equipped tractors for a minimum of two years, it is important to initiate the fleet evaluation program as quickly as possible. Initiating such a study in the very near future results in the necessary data being available in the early 1990's. Thus, it is imperative that this portion of the research be conducted in parallel with the Phase I program discussed previously. The research program needed to prove the feasibility and practicality of adapting these new technology concepts to U.S. vehicles is outlined in Figure 41.

<u>Phase III of the Program</u>

The objective of the next step in this overall program to improve the stable braking capability of air-braked medium/heavy trucks would be to achieve the maximum practical limit braking performance possible. It would build on the improvements expected to result from the first two portions of the program.

Ultimately, a vehicle's stopping performance is limited by the overall amount of brake force capacity that foundation brakes can generate and by the traction properties of the vehicle's tires. Truck brake force capacity on domestic vehicles is already at its limit with the exception of front wheel brakes. The power of this part of the system could be increased as could tire longitudinal traction. Research is necessary to understand the trade-offs involved in achieving these objectives and to establish reasonable goals for product development by the industry.

A continuing need also exists to keep abreast of innovative brake system technology, both from the standpoint of quantifying the performance improvement offered by such devices and evaluating the effect of the new technology on the current brake system -- especially to ensure that compatibility is not negatively impacted. Examples that could arise include: intermixing units with wedge and disc brakes, or units with and without load sensitive brake proportioning systems, or electric instead of pneumatic control, etc. In-fleet evaluations of performance, reliability, maintainability, and cost would be a major part of this effort.

This part of the overall program would, in general, follow the previously discussed research. It is shown diagrammatically in Figure 42.

Figure 41.
Truck Brake Performance Improvement Program
Phase II

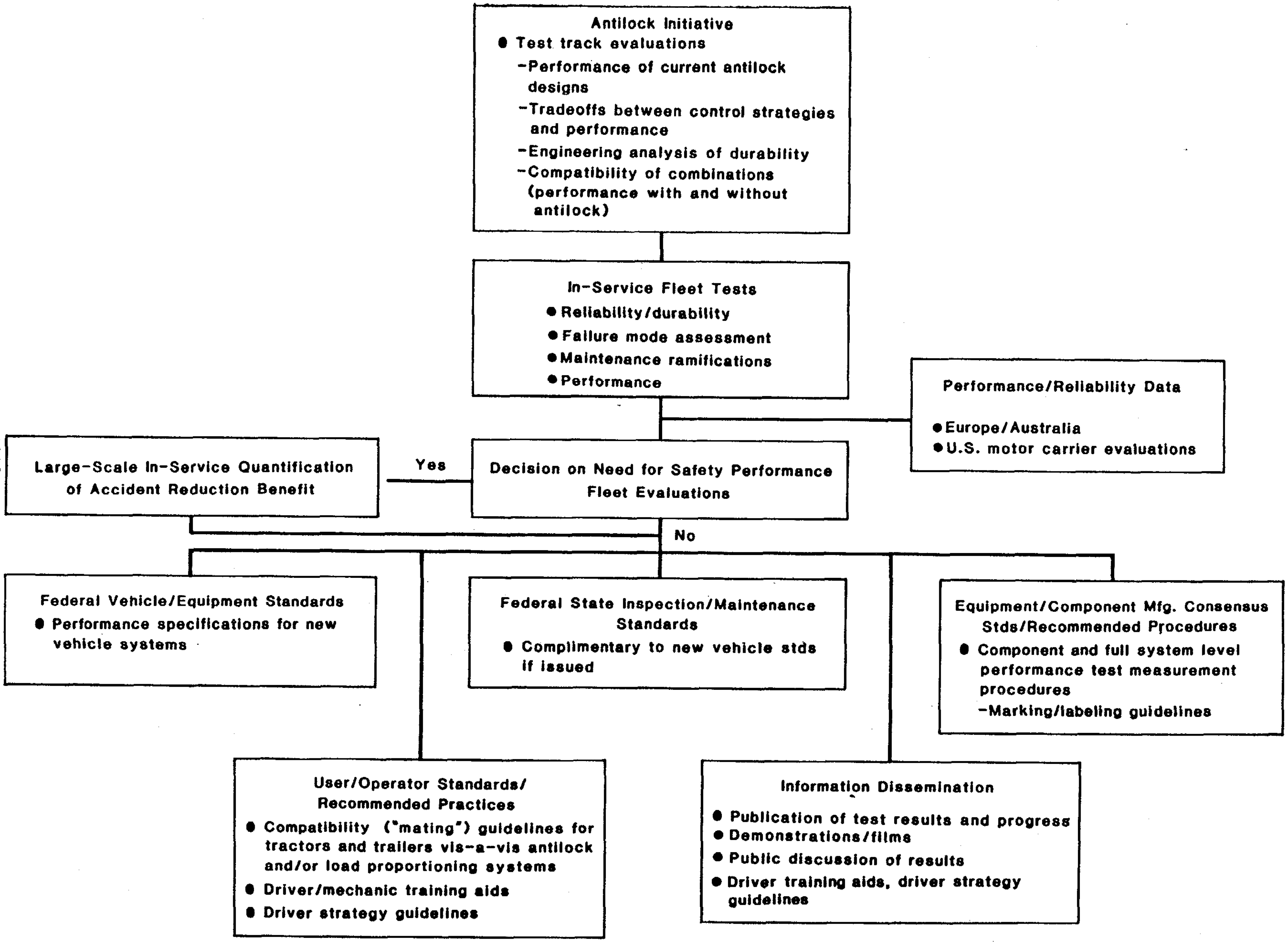


Figure 42.
Truck Brake Performance Improvement Program
Phase III

Alternative/Innovative Brake Design Evaluations (Test Track)

- Evaluate safety performance gains of:
  - -Load-sensitive brake proportioning
  - -Wedge/disc
  - -Electronic activation
  - -Other, new systems in terms of:
  - --ability to maintain adjustment
  - --uniform torque output over service life

Increased Front Wheel Brake Force Capacity (Test Track)

- Assess performance gain associated with bigger brakes
- Evaluate ramifications on:
  Steering and suspension systems and driver acceptability
- Measure steering response characteristics of vehicles with:
  - -increasing amounts of brake torque
  - -various types of steering aids (e.g. offset kingpin systems, power steering)
- Refine test measurement procedure for establishing steering response characteristics

Tire Traction (Test Track/Lab)

- Assess range of longitudinal and lateral traction capability of today's tires
- Evaluate tradeoffs between
  - -Traction
  - -Wear
  - -Cost
  - -Durability
- Parametric tests
  - -Establish performance range as a function of:
    - -Compounding/brand
    - -Wear
    - -Tread pattern, etc.
  - -Develop measurement methodology

Fleet Evaluation of Promising Tecnnology

- Performance
- Reliability
- Maintainability
- Cost

Federal Equipment Standards

- Upgrade system performance requirements as appropriate

Equipment/Component Mfg. Consensus Standards

- Develop tire traction measurement procedure
- Develop traction rating scheme
- Establish performance goals for product development by the industry

Information Dissemination

- Publish test findings
- Fabricate a hybrid state-of-the-art vehicle and demonstrate its capability
- Publish ratings

Part of this portion of the research program would be directed towards evaluating the claim that European designed heavy trucks have a brake system which provides stable, short stopping distances over a wider range of operating conditions than do U.S. designed heavy vehicles. This claim is based on the fact that all trucks in Europe have large front brakes, balanced brakes, automatic brake adjustment systems, power steering, and load-sensitive brake proportioning as standard equipment. European vehicle inspection programs also reportedly result in superior maintenance compared to that typically found in the U.S. In addition, several European countries presently are actively promoting the notion of requiring antilock systems on all medium/heavy vehicles.

Despite differences in the ways vehicles are designed and used, it is important to study the approaches other countries have taken to ensure that medium/heavy trucks are designed, produced, and operated with good braking performance. As a first step in this overall long range assessment effort, the Agency has purchased and is evaluating a European designed tractor-trailer combination-unit. These vehicles meet all of the requirement of ECE regulations. The results of this test program will provide data to allow direct comparison of the dynamic performance of vehicles designed in Europe versus those designed in the U.S.

The European experience could be particularly instructive, since the requirements contained in ECE Regulation No. 13 attempt to address many of the same problems that the research program proposed herein would address. Understanding the ECE new-vehicle requirements is not enough, however, since the overall effectiveness of their approach is greatly influenced by the mandatory periodic (at least yearly) inspections of truck brake systems that the government performs. These inspections are very extensive, time-consuming, and costly (for example, they involve vehicle tests on dynamometers) and involve essentially blueprinting the vehicle. Such an extensive inspection ensures that the replacement parts and maintenance practices have not negatively affected vehicle performance in braking. The advisability of applying such an approach to the U.S. trucking industry would need to be carefully studied.

THE PERFORMANCE CHARACTERISTICS OF MEDIUM AND HEAVY TRUCKS IN MANEUVERS INVOLVING STEERING

The steering response characteristics of a vehicle are one of the principal descriptors of its safety performance capabilities. In addition to braking capabilities, these properties define the inherent limits over which a vehicle can be safely operated.

Because of size and other physical properties of trucks, (principally their dimensional height above the ground and the fact that many are articulated vehicles) it is obvious that trucks have distinctly different and unique handling properties compared to passenger cars. Simply stated, they can not be steered around corners, change lanes, or avoid unexpected obstacles as quickly as a car can, nor are they able to make right-angle turns the same way cars can without experiencing problems.

This section of the report deals with the properties of trucks that define their steering-related stability and control limits. A great deal of research has been done on this subject since the early 1970's. As a result, considerable progress has been made in identifying the maintenance-related, design, and driver control factors which increase instability tendencies. Each of these factors usually play a role in truck accidents involving instability and/or loss-of-control. (In this report, these tendencies are described in terms of the increased likelihood they create for producing accidents rather than as absolute and discrete differentiations between "safe" and "unsafe" vehicles).

Rollover

Rollover is an easily distinguishable accident mode common to heavy trucks. Rollover occurs when the lateral acceleration imposed on a truck exceeds the "threshold" that it can sustain. The lateral acceleration arises most commonly from cornering and/or cross slope on the road, although other factors may contribute, such as lateral impacts on low barriers or curbs, tires digging into soft earth, etc. In trucking operations, rollovers happen when the level and duration of the imposed lateral acceleration is sufficient to roll the vehicle to an angle such that the driver can no longer correct for the condition.

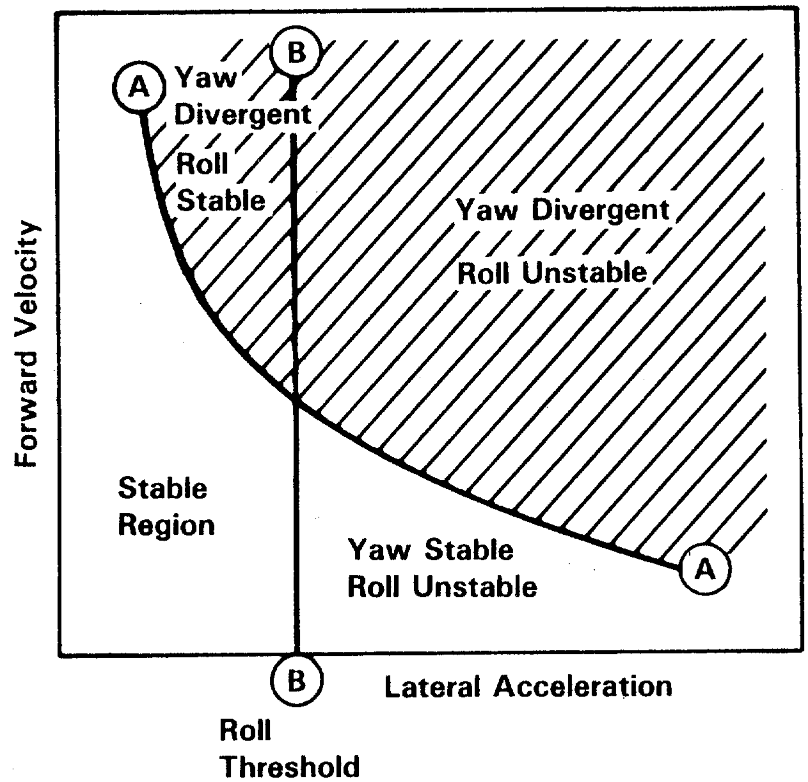
In practice, directional and roll response cannot be separated. Both areas of concern regarding yaw performance -- i.e., yaw stability of power units during cornering and lightly damped yaw response of coupled units which tend to amplify lateral acceleration levels toward the rear -- can generate vehicle motions which ultimately exceed the vehicle's basic roll stability. While the limit of such vehicles is defined by a yaw instability, the safety-related consequence of exceeding the limit may be rollover.

Yaw divergence can be encountered with heavy vehicles during braking maneuvers due to wheel lockup and loss of lateral traction. The concern and attention here, however, is directed only to the occurrence of yaw divergence during steady turning at relatively high forward speeds. This instability mode occurs primarily with loaded vehicles.

One way of illustrating the yaw and roll stability relationship is to plot for a given vehicle, its yaw divergent or "critical" velocity as a function of lateral acceleration (see Figure 43, line A-A). Also shown on the same plot is a vertical line B-B which defines the rollover threshold for the given vehicle. The yaw/roll stability regime for this vehicle is then defined as that velocity/lateral acceleration area lying to the left of the combined curves.

The yaw/roll stability plot is comprised of four distinct regions: (1) the stable region, (2) the yaw stable/roll unstable region, (3) the yaw divergent/roll stable region, and (4) the yaw divergent/roll unstable region. At low speeds and increasing levels of lateral acceleration (tighter and tighter low speed turning), the principal stability concern is rollover. At elevated speeds, as lateral acceleration increases, the principal stability concern is yaw divergence prior to reaching the rollover threshold. The danger of yaw divergence, if not attended to by corrective driver steering control and/or reduced speed is that it will quickly lead to a further increase in a vehicle's lateral acceleration and thereby precipitate a rollover.

Figure 43. Yaw/Roll Stability Plot



Vehicle Factors Affecting Roll Stability

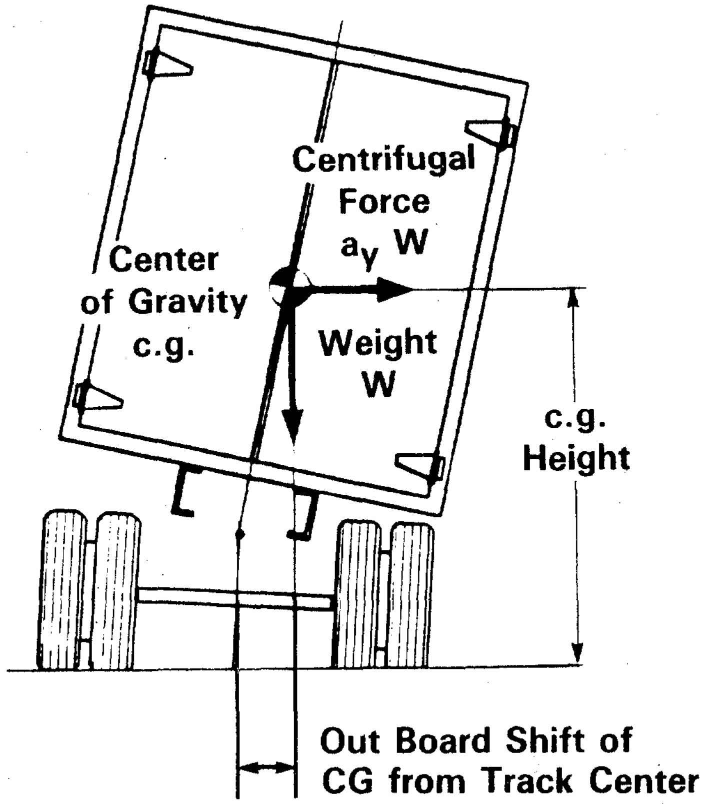
The mechanisms that influence commercial vehicle roll stability in a steady turn are well understood. Figure 44 illustrates that as a vehicle undergoes a turn, it experiences a centrifugal force pulling outward from the center of the turn through the vehicle's center of gravity (c.g.). This force tends to roll the vehicle outward from the turn, and if large enough, will cause the vehicle's inside tires to lift from the ground and roll the vehicle over.

The magnitude of this force is equal to the weight of the vehicle (W) times the lateral acceleration (a_y) generated by the turn. As the turn becomes more severe, lateral acceleration increases, causing an increase in the centrifugal force. Thus, the roll stability limit of the vehicle is generally defined by the maximum level of lateral acceleration which a vehicle can sustain without rolling over.

In addition to the centrifugal force, as the vehicle rolls outward in a turn, its center of gravity (c.g.) tends to shift outward relative to the vehicle's track. This outward shift of the c.g. also tends to promote rollover, serving to lower the roll stability level.

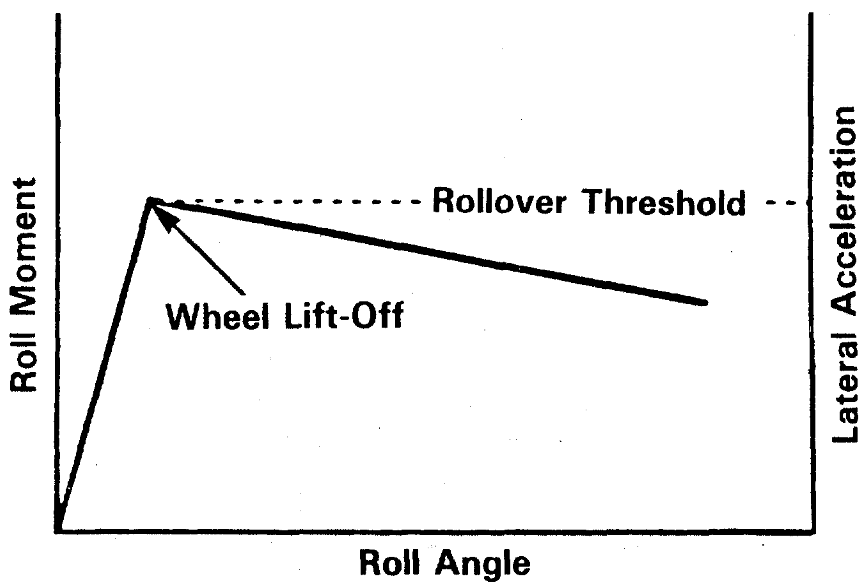
In steady turning situations where the driver must follow a constant radius (e.g., exit ramps), a static or quasi-static, rollover threshold can be defined from an analysis of the moments acting on the vehicle. The

Figure 44. A Heavy Truck in a Left Turn



rollover threshold is described by the lateral acceleration level at which the net roll-resisting moment reaches its maximum. Figure 45 illustrates this threshold on a plot of roll moment versus roll angle for a typical angle on the vehicle. The vehicle is stable so long as the lateral acceleration does not exceed the peak level of the curve. When it does exceed the peak, it is exceeding the vehicle's ability to resist rollover. At this point irrecoverable rollover begins.

Figure 45. Roll Response of a Truck



A number of vehicle parameters have been identified which affect the roll stability limit of a vehicle. Generally, these parameters either determine the direct effectiveness of the centrifugal force in generating rollover, or they contribute to determining the amount of outward shift of the center of gravity in a given turn.

The ratio of half of the track width to c.g. height is the most basic vehicle parameter determining vehicle roll stability. It is one parameter which establishes "the direct effectiveness of the centrifugal force in generating rollover." As the ratio is increased, either by increasing track width or decreasing c.g. height, the roll stability of the vehicle is improved.

Other vehicle parameters have a significant effect on roll stability, but they do so through influencing the secondary mechanism of the outboard shift of the c.g. due to roll. Recognizing, however, that this "secondary" effect can reduce roll stability on the order of 50 percent relative to the "rigid" vehicle, these parameters are significant. The more important vehicle properties include: 1) the general level of roll stiffness of the vehicle suspensions and tires, including the influence of suspension lash; 2) suspension geometry, in particular, the heights of the suspension roll centers; and 3) the distribution of stiffness among the various suspensions of the vehicle.

Vehicle properties that are important to rollover are affected by current practices in assembling and loading commercial vehicles, namely,

1) Trailers built in van and platform configurations have a loading floor height which is approximately 25 percent greater than the effective "half-track" dimension. Thus any payload placed on that floor is strongly capable of destabilizing the vehicle in roll.

2) Many U.S. trucks are used to haul relatively low-density freight. This type of cargo is commonly stacked to nearly the maximum height dimension (which is constrained only by bridge clearance considerations) of the trailer, thereby raising the effective c.g. height of the vehicle.

3) In order to reduce costs and design and manufacturing complexity, bulk-commodity tank trailers are commonly constructed as either circular or elliptical cylinders, without drop bottoms. As a result their c.g. heights are also typically far above the level of the half-track value.

4) Tractor and trailer suspensions do not employ roll stiffness levels which are uniformly proportioned to the loads carried on the respective axles.

5) Tractors steering axles are conspicuously deficient in roll stiffness level, given the level of front axle load which is carried.

6) Leaf-spring suspensions employed on tractor drive axles and trailer axles commonly incorporate substantial levels of spring lash which serves to reduce the effective roll stiffness.

7) Certain truck suspensions have comparatively low roll-centers, causing a greater portion of the imposed roll moment to be borne by the suspension springs.

8) Truck and tractor frames have low levels of torsional stiffness, rendering the "roll-assistance" of the front axle suspension less effective.

9) The lash present in fifth wheel assemblies can degrade the roll stability of combination-unit trucks having very high centers of gravity.

10) Certain types of truck tires, especially wide-base singles, possess rather low levels of vertical stiffness such that roll stability is reduced.

11) Sloshing liquid loads serve to contribute both static and dynamic effects which degrade roll stability.

12) Laterally-offset solid loads, occurring either due to in-transit shifting of the load or simply due to an inherently asymmetric payload, serve to directly reduce the effective "half-track dimension."

In transient maneuvers, such as a lane change, the onset of rollover is not as directly related to the simple summation of moments in the roll direction, but will also depend on the dynamics of the vehicle in the maneuver. The dynamics impact on the amplitude and duration of the lateral acceleration exposure determines whether roll energy may have already been built up by preceding rotations of the maneuver.

The tendency for rearward amplification arises directly from inherent properties of the vehicle's design and can result in rollovers. As implied by the name, "rearward amplification," the severity of a maneuver executed at the front of the vehicle in response to driver actions, is increased in intensity at points further rearward in the vehicle or combination. With combination-unit trucks, an attenuation occurs such that the driver can successfully operate the tractor for brief intervals at lateral acceleration levels beyond the rollover threshold of the combination. In the case of doubles combinations, however, rearward amplification exposes the rear trailer to lateral acceleration levels greater than those experienced by the tractor. The presence of rearward amplification reduces the effective maneuvering level that the driver can execute without causing rollover.

Outboard off-tracking is a second form of dynamic performance that may potentially compound the risk of rollover. In some high-speed turning maneuvers, sufficient lateral acceleration is generated such that the rear axles in the vehicle train move out beyond the path steered by the driver at the front of the tractor. This increases the potential that these axles may impact with curbs or low barriers producing an impulse of lateral acceleration sufficient to trip the vehicle to an irrecoverable roll angle or the tires may drop off of a pavement edge adding to the effective cross slope experienced by the trailer. Or, the tires may encounter gravel or other material reducing their cornering traction and allowing the trailer to swing to a higher slip angle condition.

The ability of drivers to sense imminent rollover in transient situations and correct for it is not well established. With single-unit trucks and combination-unit trucks there is some possibility that the driver can sense imminent rollover and perhaps make steering corrections. The lack of knowledge in this area may be somewhat obscured by the fact that many of these vehicles become yaw unstable before rollover, impeding the driver from taking appropriate action. In the case of the second trailer of a doubles combination, the driver cannot avoid a rollover by his steering actions because of his inability to feel what the trailer is doing, and the delays between steer inputs and responses at the end of the train. By and large, the base of knowledge at the fundamental level of driver lateral acceleration demand in the operation of heavy duty vehicles is too deficient to support any understanding of the driver/vehicle combination in rollover accident causation.

Thus, in transient maneuvers, an absolute rollover threshold cannot be defined as simply as for the static case. It must be defined in terms of the peak levels achievable in specific maneuvering situations. Although the static threshold is logically a relative measure of a truck's propensities for rollover accidents, in any transient maneuver the dynamics of the vehicle and the exact nature of the maneuver will influence whether a rollover actually occurs.

Prevalence and Characteristics of Rollover Accidents

Rollovers constitute a very visible and serious type of commercial vehicle crash. Rollover is directly coded in most accident data files. Shown in Table 42 is a compilation of the relative occurrence of rollovers as reported in several representative accident data files. Although vehicle rollover is involved in from 4 to 9 percent of all medium/heavy truck crashes, it accounts for approximately one third of the single-vehicle accidents. Rollover occurs in approximately 15 percent of the fatal crashes and is a contributory factor in nearly 60 percent of the medium/heavy truck occupant fatalities.

Although rollovers occur most frequently on dry, straight roads, as do all accident types, they are disproportionately more prevalent on curved roads (see Table 43).

Compared to other types of accidents, rollovers are not disproportionately overrepresented on any one particular roadway type (i.e., Interstates, U.S. routes, etc.) versus another, but they do occur more frequently completely off the road (37.1 percent vs. 7.6 percent) than do other accident types.

Driver actions, prior to the crash, also contribute to many rollovers, as can be seen in Table 44.

Other vehicle factors, such as component parts failures or deficiencies and shifting loads, are overrepresented in this class of accidents (see Table 45).

Table 42. Medium and Heavy Truck Involvements in Rollover Accidents

Accident File	Number of Vehicle Involvements in Rollover Accidents	Percent of Total Vehicle Involvements In Accidents
FARS 1983		
Single and combination-unit trucks	731	14.7%
BMCS 1983 *	2,155	8.7%
National Accident Sampling System (NASS)		
Single and combination-unit trucks	25,892	6.6%
Texas 1981-1983		
Combination-unit trucks	1,618	7.4%
Single-unit trucks	1,276	5.5%
Washington 1981-1983		
Combination-unit trucks	729	7.6%
Single-unit trucks	316	3.8%

* Number and percent of accidents.

Table 43. Environments in Which Combination-Unit Truck Rollovers Occur

Type of Environment	Percent of Combination-Unit Truck Accidents	
	Texas (1981-1983)	Washington (1981-1983)
Dry/Straight Roads		
Rollover accidents	50.6%	14.0%
All accidents	73.4%	44.7%
Slippery roads		
Rollover accidents	23.6%	31.5%
All accidents	19.7%	34.1%
Curved Roads		
Rollover accidents	25.8%	54.5%
All Accidents	6.9%	21.2%

Table 44. Driver Contributing Factors in Rollover Accidents Involving Combination-Unit Trucks

Driver-Related Factors	Percent of Accidents Combination-Unit Truck	
	Texas (1981-1983)	Washington (1981-1983)
Loss-of-control/skidding		
Rollover accidents	5.5%	19.2%
All accidents	3.1%	7.9%
Avoiding objects or vehicles		
Rollover accidents	6.7%	7.1%
All accidents	2.7%	2.7%
Speeding		
Rollover accidents	59.6%	45.1%
All accidents	21.9%	14.6%
Inattention		
Rollover accidents	1.1%	10.6%
All accidents	0.4%	9.8%
Falling asleep		
Rollover accidents	5.2%	4.4%
All accidents	1.5%	1.1%

* Note: These percentages are not additive, since several of these factors may have been present in the same accident.

Table 45. Other Vehicle Factors Contributing To Rollover Accidents*

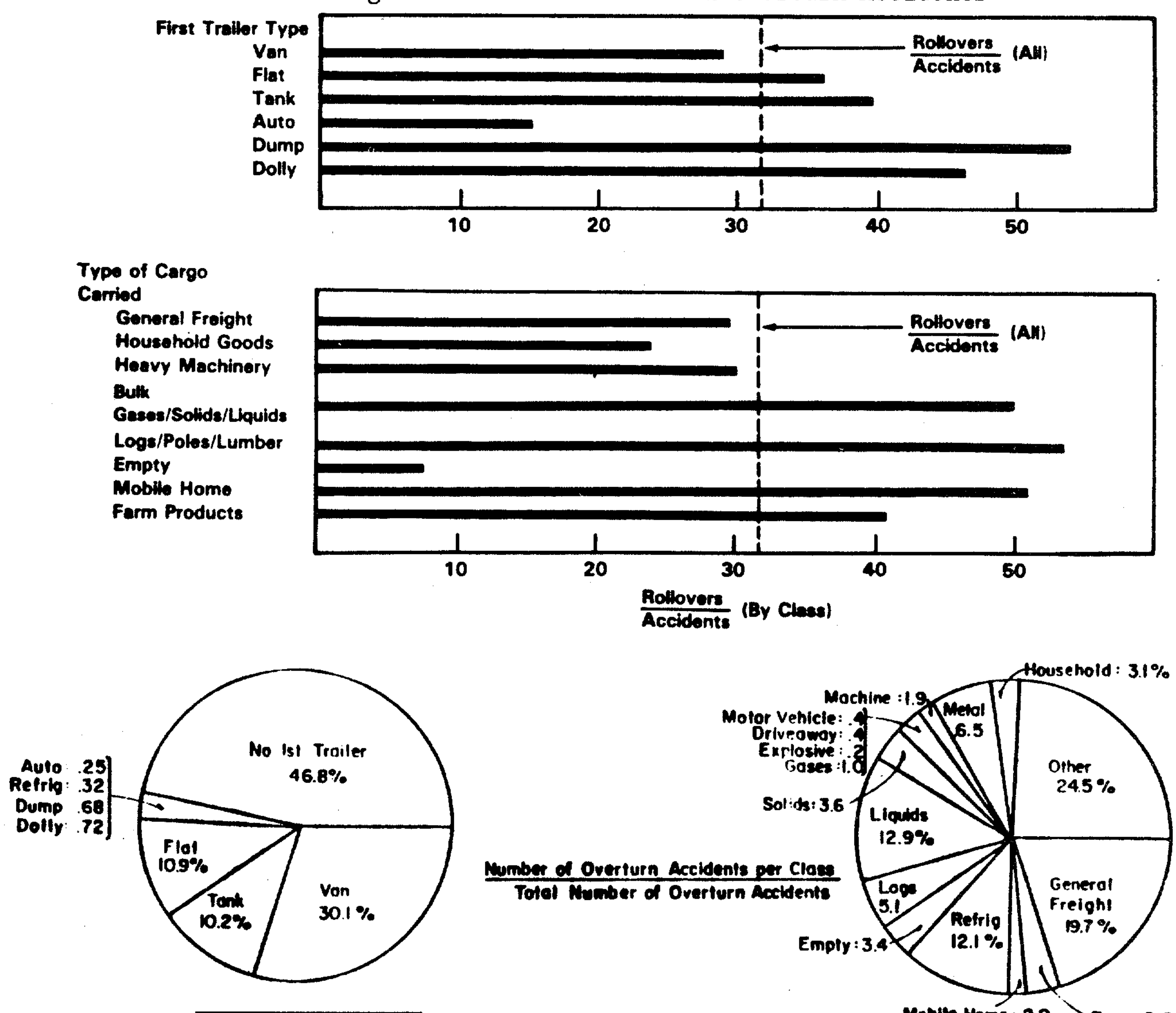
Vehicle Contributory Factors	Percent of Accidents Combination-Unit Truck	
	Texas (1981-1983)	Washington (1981-1983)
Shifting or lost load		
Rollover accidents	Not	4.7%
All accidents	Available.	2.7%
Deficient brakes		
Rollover accidents	4.4%	10.5%
ALL accidents	2.3%	3.4%
Deficient tires		
Rollover accidents	3.0%	7.2%
All accidents	1.0%	2.4%
Other deficiencies		
Rollover accidents	7.4%	10.4%
All accidents	3.1%	8.9%

*Note: These percentages are not additive, since several of these factors may have been present in the same accident.

The BMCS data file also indicates, in a limited, way, the type of vehicle and cargo involved in rollovers. Figure 46 presents data on the distribution of all single-vehicle, non-collision overturn accidents for the years 1976-1981 by body and cargo type. The data are presented in the form of two bar graphs and two pie charts. The bar graphs indicate the number of rollovers as a percentage of the total number of accidents for the specific vehicle type. Also shown is a vertical reference line indicating the same parameter but for the entire accident-involved population. Thus, any bars extending to the right of this reference line can be considered to be overrepresented. The pie charts indicate the number of rollover accidents, by class as a percentage of the accident-involved population.

By first trailer type, the graph shows that high c.g. tank and dump types and multiply-articulated vehicles are over-involved in rollovers. Flatbed trailers, which are slightly overrepresented, often carry asymmetric and/or high c.g. loads as well. The majority of cargo types overrepresented are also easily identified as having high c.g.'s.

Figure 46. Distribution of Overturn Accidents*



* Based on BMCS accident data for 1976-1981

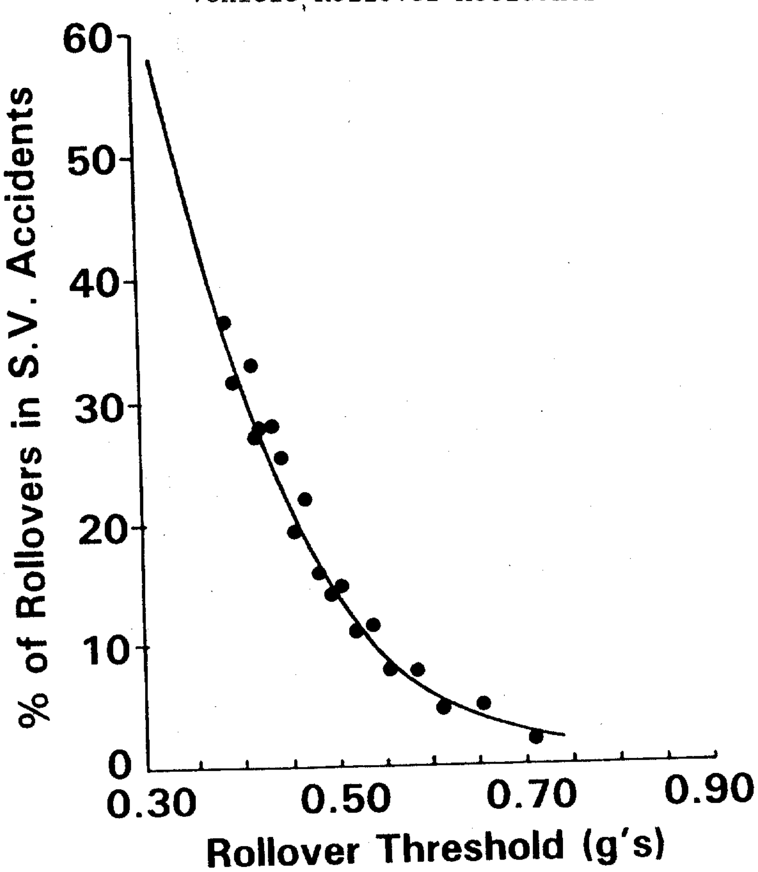
Ervin et al (1980), utilized BMCS accident data for the years 1976-1979 to derive a relationship between rollover threshold and the percentage of rollovers in single-vehicle crashes. Such a relationship constitutes a key predictor of the effects of various vehicle design changes, with regard to rollover accident involvement.

The BMCS data file is one of the few accident data files which contains both a detailed description of a truck involved in a crash and its gross vehicle weight.

Rollover events are recorded in the BMCS data file only if they occur in single-vehicle accidents. However, this represents the dominant portion of the medium/heavy truck rollover problem.

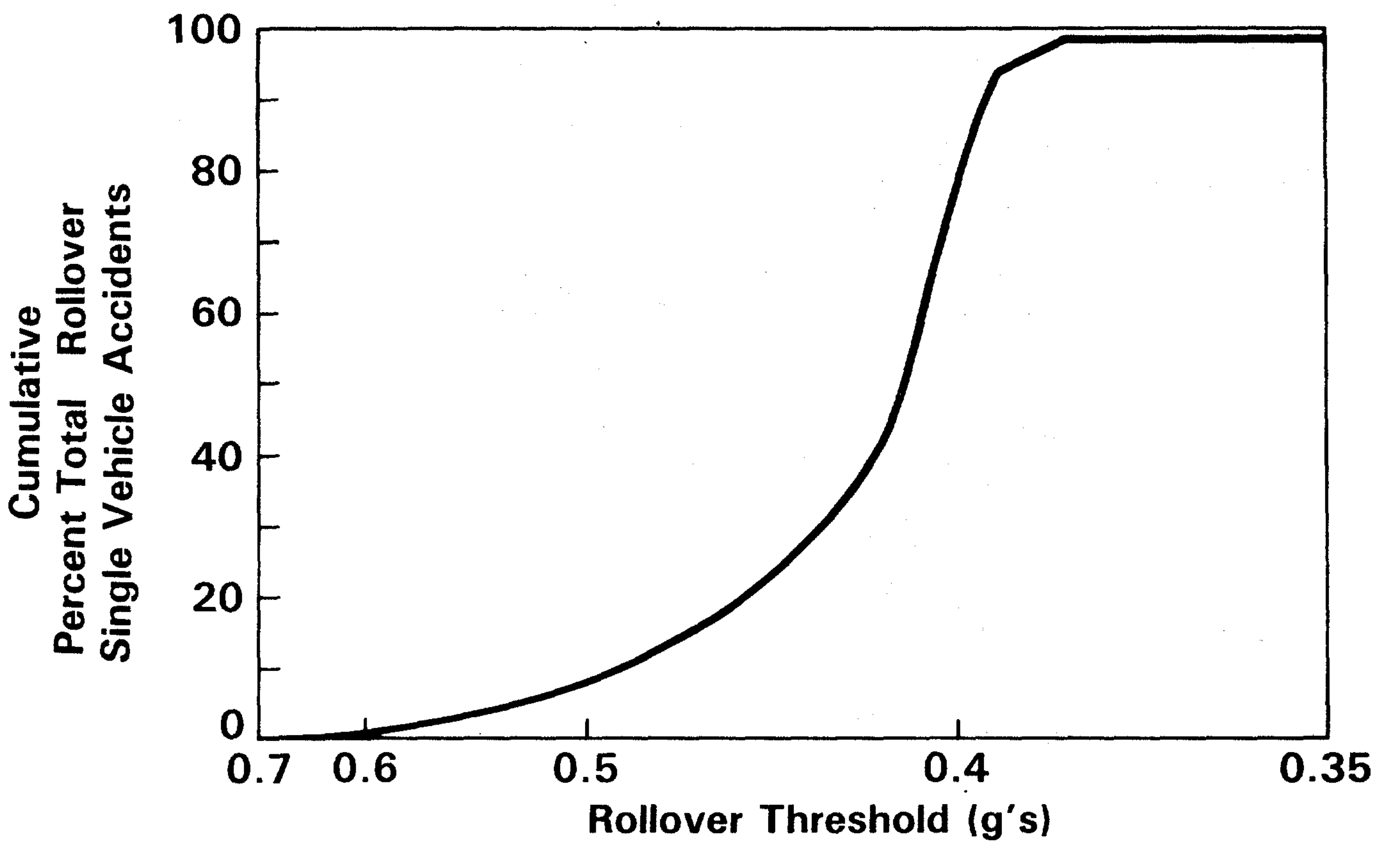
A vehicle configuration -- three axle tractor, two-axle van body trailer -- was selected which was prevalent and whose rollover threshold could be reasonably approximated, given the gross weight. The BMCS file was sorted to identify the occurrence of rollover at each nominal level of gross weight for all vehicles of the selected type. An algorithm was developed for locating the nominal height at which the center of gravity (c.g.) of the payload would be placed. Using this c.g. height, the rollover threshold was calculated for each level of gross vehicle weight. The data were then plotted, as shown in Figure 47, illustrating the relationship between the static rollover threshold and the percentage of rollovers actually occurring in single-vehicle accidents.

Figure 47. Relationship Between Rollover Threshold and Single-Vehicle Rollover Accidents



Although the technical question as to whether the static rollover threshold alone is a suitable measure of rollover propensity for different classes of vehicles remains, this plot is, nevertheless, very instructive. First, it shows that rollover is a loaded vehicle problem. Second, it illustrates the fact that small changes in the static rollover threshold of a vehicle can dramatically reduce that vehicle's propensity to roll over. This latter fact is illustrated more clearly in Figure 48, which is a slightly different representation of the data plotted in Figure 47.

Figure 48. Single-Vehicle Rollover Accidents

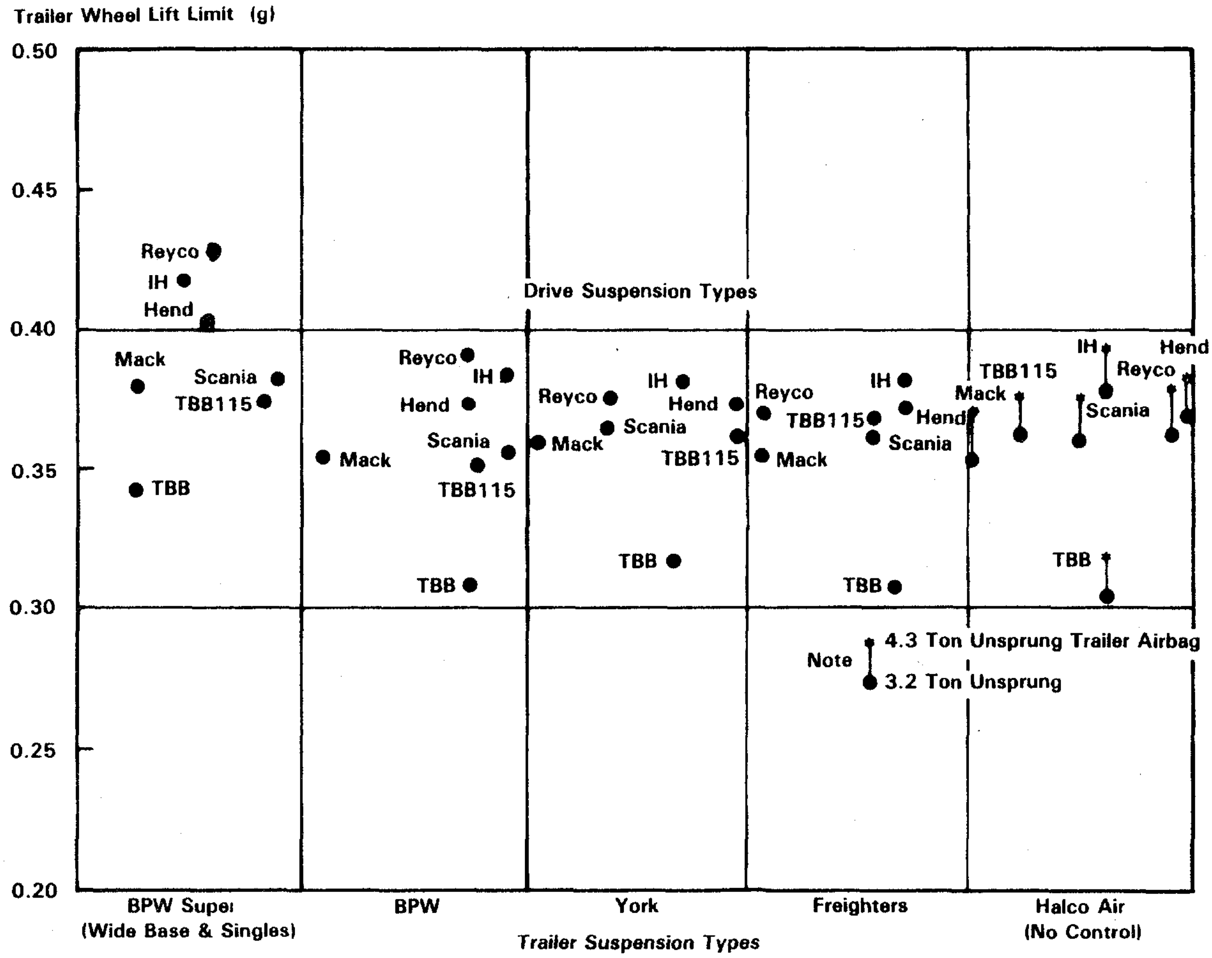


Measuring Rollover Thresholds

Mai and Sweetman (1984) utilized a tilt table to determine the rollover threshold of typical Australian heavy vehicles. Figure 49 shows data for trailer wheel lift lateral acceleration versus the five trailer suspension types for each of the seven prime mover suspension types. (The authors noted that the differences between "rollover" and "first wheel lift" are generally small -- averaging only .01 g).

These data, which include suspension types utilized on U.S. vehicles, indicate that typical static rollover thresholds range from .36 to .44 g.

Figure 49. Stability Performance of Suspension Combinations on "Standard" Vehicle



Tractor Suspensions Shown in Figure 49

Mack	Single-point 'Camelback' tandem drive suspension.
Torsion Bar Bogie (TBB)	Kenworth torsion bar tandem drive suspension with older type 1 5/8" torsion bars.
Scania	Non-reactive four-spring drive suspension with anti-roll bar on rear axle.
TBB115	Kenworth torsion bar tandem drive suspension of new design with 1 5/8" torsion bars inclined 1.25 deg. to the chassis.
International Harvester (IH)	Conventional four-spring drive suspension (15 leaves).
Hendrickson	Hendrickson RT380 walking beam tandem drive suspension.

Trailer Suspensions Shown in Figure 49

BPW (wide)	Newer-generation BPW VA six-spring trailer suspension with taper leaves, anti-roll bars, and widened (1200 mm) spring centers compatible with wide single tires.

BPW	Newer-generation BPW VA six-spring trailer suspension as above except with 1,000 mm spring centers to accommodate conventional dual tires.
Freighters	Conventional TAA-35 Freighters Industries six-spring trailer suspension.
Halco Air	Halco air bag tri-axle trailer suspension.
York	Conventional six-spring trailer suspension.

The typical static roll thresholds of current vehicles (suspension systems) are such that the potential for rollover is high. Design changes and/or better matching of truck and trailer suspensions would result in a substantial raising of these rollover thresholds. Referring to Figure 48, a reduction of nearly 90 percent in the number of single-vehicle rollovers could be anticipated if the rollover threshold was changed from 0.36 to 0.44 g.

The dynamic behavior of modern trucks could be improved in a number of ways. The most effective way to reduce rollovers is to control center-of-gravity height and use wider vehicles. Wider (102-inch) vehicles have the potential to reduce loading heights as well as permitting wider track and suspension spreads. It has been estimated that reductions up to 35 percent in rollover might be possible with combination-unit trucks operating with "medium-density freight," if both tractor and trailer were 102 inches wide. Smaller, but significant, reductions are also possible by optimizing suspension system properties with an eye toward maximizing compatibility of tractors and trailers. The mechanical properties of vehicles affecting the static rollover threshold are sufficiently well understood that it is possible to improve performance at the initial design stage.

Each of these changes involve some penalty to the trucking industry, either in higher initial cost or weight. Wider vehicles and monitoring the center-of-gravity height of loaded vehicles will add to the difficulty and expense of general operations. Suspension improvements for rollover may incur penalties in ride and/or cargo damage. By and large, the full implications of changes that will improve rollover accident experience need to be investigated.

Trailing Fidelity

In the operation of combination vehicles (i.e., tractors pulling one or more trailer units), it would be desirable for the tires of each of the trailing units to track the same path as the tires of the tractor under all operating conditions. This would ensure a minimum swept path of the vehicle, as well as each trailer experiencing the same severity of maneuver as the tractor. Under these conditions, the driver would be in control of trailer behavior to the same extent that he was in control of tractor behavior.

"Trailing fidelity" refers to this ability of trailers to precisely follow the tractor. Unfortunately, the basic properties of conventional commercial vehicles result in trailing fidelity that is often less than desirable. Three performance areas are of concern:

- o Low-speed off-tracking
- o High-speed off-tracking
- o Rearward amplification

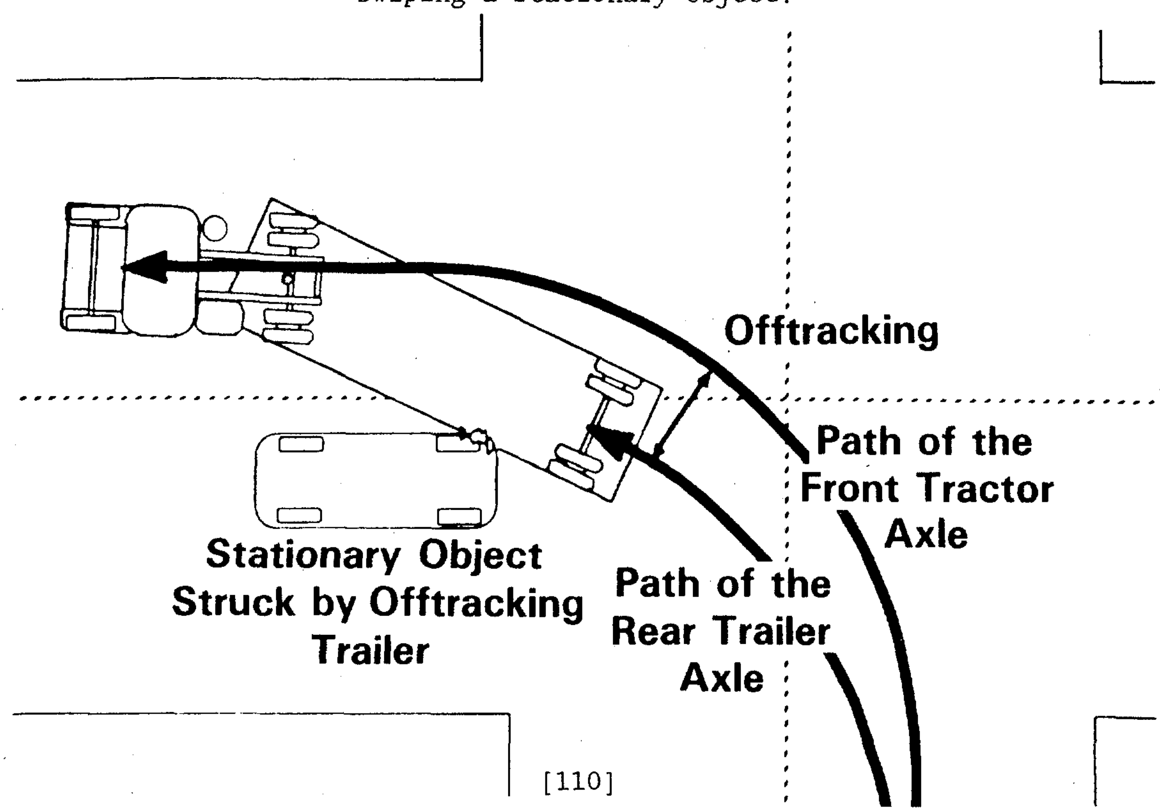
Off-tracking refers to the lateral dimension by which trailing axles fail to precisely track preceding axles during steady-turning maneuvers. Rearward amplification refers to failure of trailers to precisely follow the towing vehicle's dynamic path during certain turning maneuvers, such as rapid lane changes.

These three performance properties are related, not only by definition (trailing fidelity), but by parametric sensitivity. That is, several individual vehicle parameters (e.g. wheelbase) have a strong influence on each of these performance properties. Unfortunately, the changes in vehicle parameters, which would improve one performance area, often degrade the other.

Low-speed Off-tracking

When traveling at low speed, all vehicles (which use steering front axles and non-steering rear axles) exhibit inboard off-tracking in low-speed cornering. This is true of cars, single-unit trucks and combination vehicles. Recognizing that, at low speed, each tire travels forward in just the direction it is pointed, it is straightforward to show that each axle of the vehicle subtends a curved path whose radius is smaller than the radius of the path of the preceding axle. Low-speed off-tracking is illustrated in Figure 50.

Figure 50. In Low-Speed Off-Tracking, Each Axle Tracks Inboard of The Preceding Axle. A Typical Accident Scenario Involves The Trailer, Side-Swiping a Stationary Object.



The extent to which a commercial vehicle will off-track at low speed is strongly related to its length, or wheelbase. Off-tracking is reduced by the addition of articulation joints. Other influences include the use of dual tires and tandem-axle suspensions, tire stiffness properties, and tire-to-road friction levels. Low speed off-tracking is depicted in Figure 51.

Low-speed off-tracking could be reduced or completely eliminated by steering the wheels of trailer or dolly axles. Largely because of its cost, however, this unconventional approach is generally only employed in specialized, exceptionally long vehicles, whose off-tracking behavior would be categorically unacceptable otherwise.

Figure 51. The Low-Speed Off-Tracking of 28 Foot Twin Trailers is Less Than The Low-Speed Off-Tracking of a Single, 45 Foot Trailer.

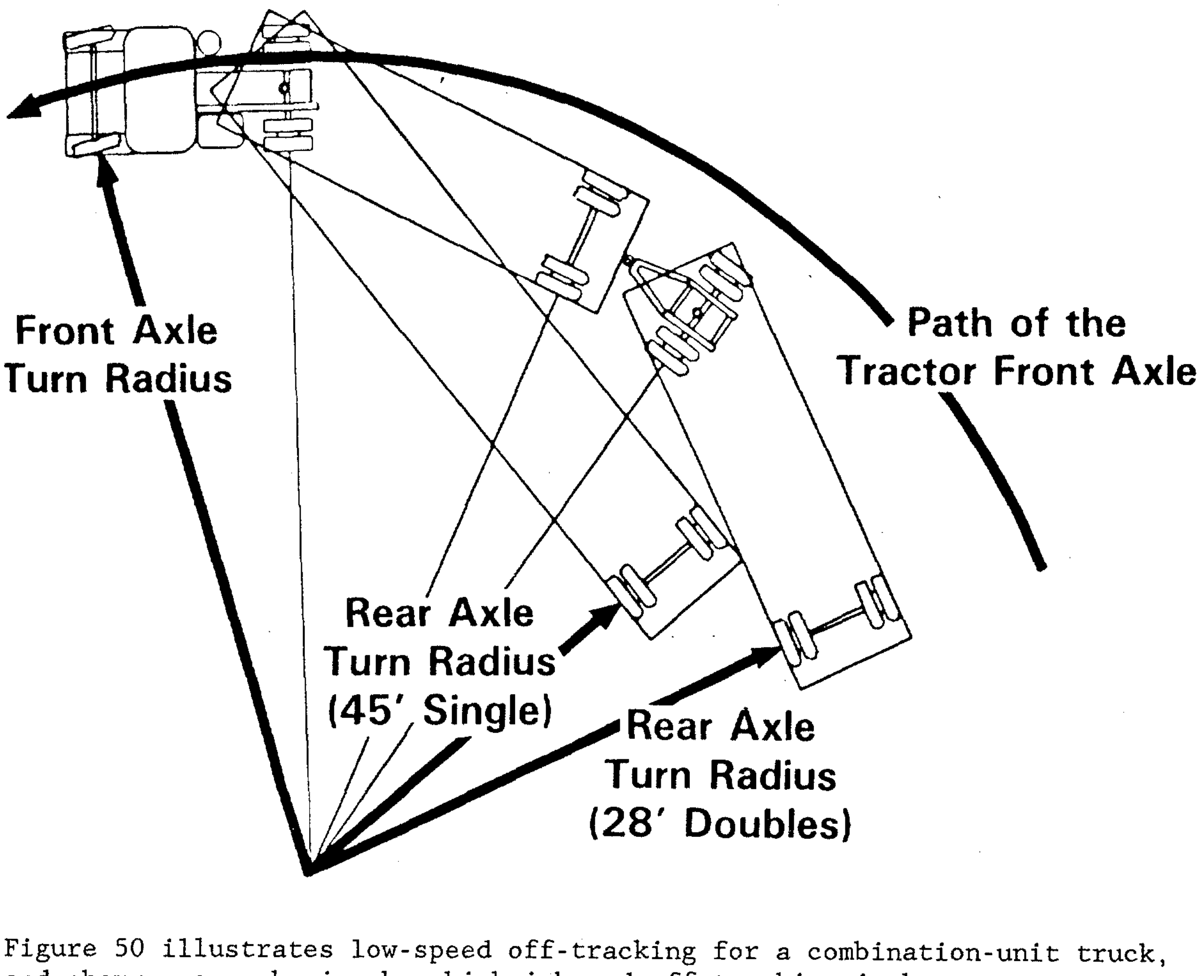


Figure 50 illustrates low-speed off-tracking for a combination-unit truck, and shows one mechanism by which inboard off-tracking is known to cause some property damage accidents. Particularly on urban roads, the trailer of combination vehicles may "side-swipe" stationary objects which have already been cleared by the tractor.

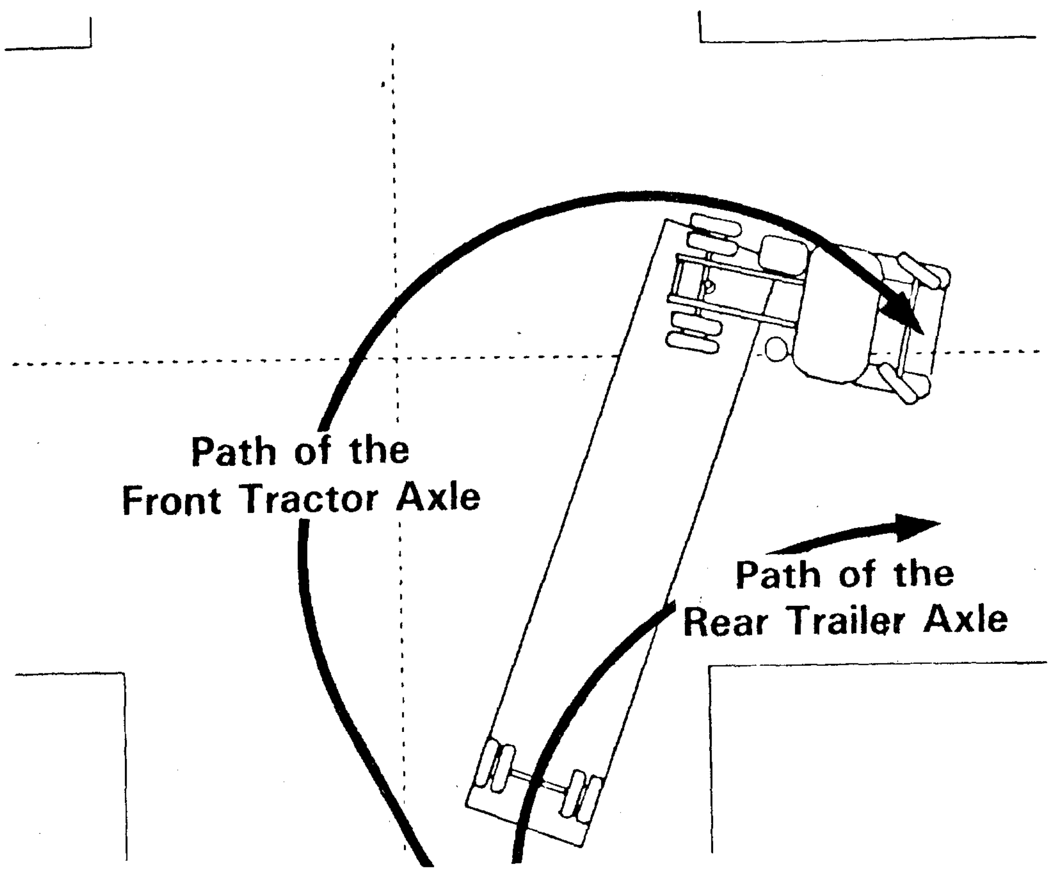
Low-speed off-tracking also causes maneuverability problems and traffic flow restriction problems. As shown in Figure 52 drivers who are well aware of the off-tracking properties of their vehicles, may swing the tractor very wide through corners to avoid trailer accidents. If the tractor protrudes into the right-of-way of oncoming vehicles, traffic flow may be disrupted. In extreme examples, there may simply not be enough space for the vehicle to maneuver.

The limited data available suggest that long, single trailer combinations experience more turning accidents than do doubles composed of two shorter trailers. These data tend to imply that the larger, low-speed off-tracking of the single was the cause of accidents. Low-speed off-tracking accidents tend to be relatively low-severity events.

The expanding use of doubles composed of short wheelbase trailers, displacing singles using longer trailers, could reduce the low-speed off-tracking problem. Optimizing the location of axles and hitch points could also reduce low-speed off-tracking. These geometric mechanisms, however, tend to conflict directly with both high-speed off-tracking and rearward amplification goals.

Controlled steering of rearward axles (dolly and trailer axles) is a potential, albeit expensive, means for improving low-speed off-tracking. If economic incentives for improved productivity were sufficient, such approaches could be used to meet off-tracking restraints with, for example, longer vehicles than are currently common.

Figure 52. To Avoid a Low Speed Off-Tracking Accident, The Driver Must Swing The Tractor Very Wide Through Urban Turns, Intruding On Other Traffic Lanes.



High-speed Off-tracking

While low-speed off-tracking is characterized by each axle of the vehicle tracking a smaller radius than the axle preceding it; the reverse is true of high-speed off-tracking. Generally, commercial vehicles exhibit outboard, rather than inboard, Off-tracking at highway speeds.

As shown in Figure 53, when cornering at speed, each tire does <u>not</u> travel in precisely the direction it is pointed. Rather, in order to develop the necessary cornering forces, each tire operates at some slip angle. The level of slip angle at each tire depends on tire properties, tire loading, and the severity of the maneuver (i.e., the level of required cornering force at that tire). When slip angles are large enough, rear axles may off-track outboard of the front axles of the vehicle.

The physical mechanisms involved in high-speed off-tracking are well understood, and mathematical treatment of these mechanisms are well developed. High-speed off-tracking is essentially composed of inboard, low-speed off-tracking plus the outboard off-tracking induced by slip angle. The latter, outboard component is large at higher speed for longer vehicles with lower cornering stiffness tires. Some vehicle properties (such as more articulation joints) which lessen low-speed, inboard off-tracking, aggravate outboard, high-speed off-tracking.

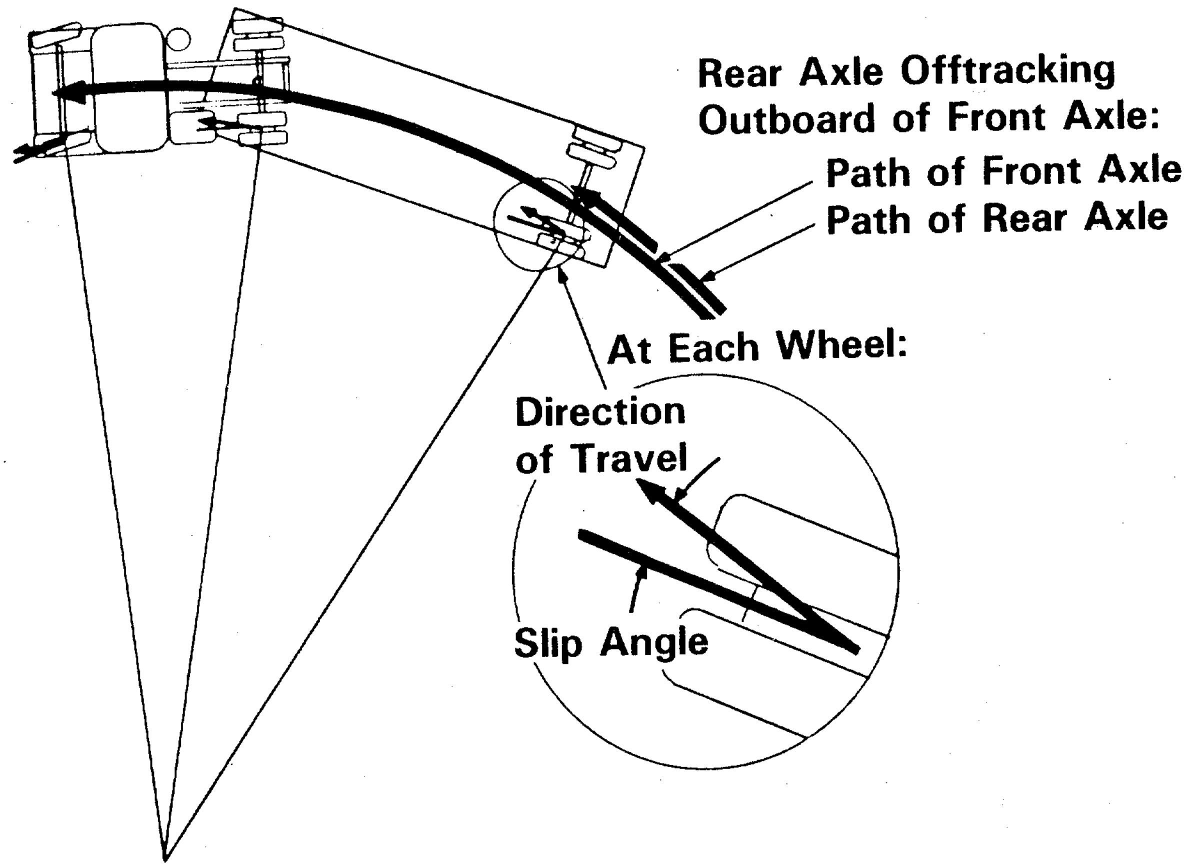
Outboard off-tracking at higher speeds could be the cause of a certain type of commercial vehicle accident. However, its overall safety significance is not clear. The accident scenario that could be envisioned as arising from this tendency would involve rollover of the (last) trailer in a high-speed turn at highway entrance and exit ramps. If a curb is present on the outboard side, trailer tires striking the curb as a result of outboard off-tracking may provide the necessary impetus to cause rollover.

Rearward Amplification

Rearward amplification refers to the trailing fidelity of articulated vehicles during dynamic maneuvers; specifically, the phenomena that the rear unit of multi-articulated combination vehicles may experience a maximum lateral acceleration which substantially exceeds that of the lead unit of the combination. This behavior, which is present in certain combination-unit trucks (having only one articulation point), appears to a much more pronounced degree in vehicle configurations having more than one articulation point (e.g., doubles, triples, and truck-full-trailers). It manifests itself most prominently in obstacle avoidance maneuvers characterized by rapid left/right or right/left steering inputs -- such as responding to a sudden, unanticipated stop by a preceding vehicle or to a vehicle pulling into traffic with insufficient headway.

It should be noted that the amplification response can be excited through steering maneuvers other than the obstacle avoidance maneuver. Other typical situations include : (a) the case of a driver who observes in his mirrors that the wheels of his last trailer are running on the shoulder and imparts an abrupt steering correction to get the wheels back on the highway, (b) the case of a driver falling asleep, drifting off the road, and then imparting an abrupt steering correction upon being awakened by the off-road ride vibrations.

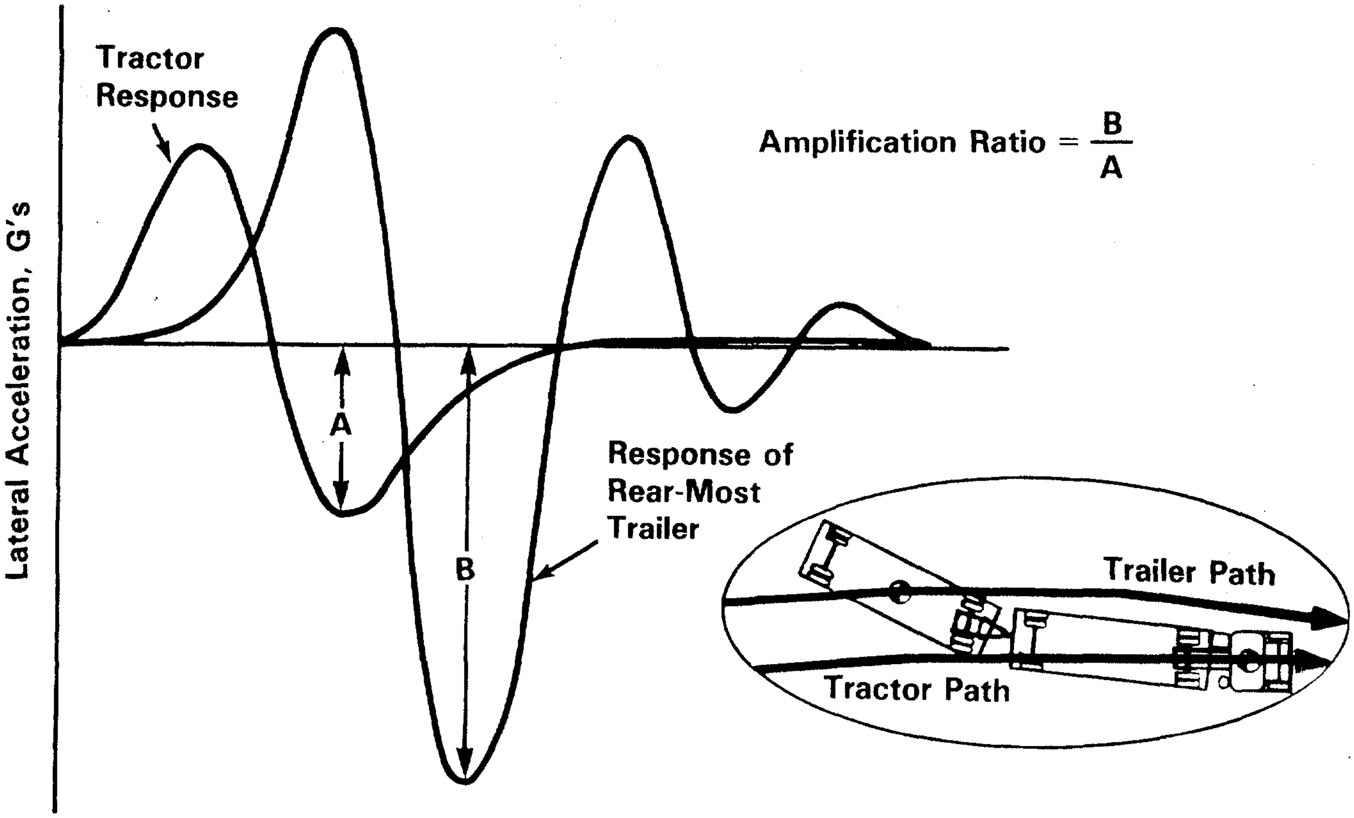
Figure 53. In High-Speed Off-Tracking, Trailers May Off-Track Outboard of the Tractor If the Tire Slip Angles Are Large Enough.



The rearward amplification phenomenon is at its worst when the following operational conditions prevail: (1) the vehicle is traveling at highway speeds (the faster the speed, the higher the amplification factor); (2) the vehicle is fully loaded (reasons pertaining to both rollover and directional response apply here); and (3) the steering activity required to avoid an obstacle or make a path correction contains a rapid reversal of the steering-wheel angle.

The safety concern, arising from this type of behavior, involves the risk that the rearmost trailing element will suffer rollover in steering maneuvers which are, otherwise too low in severity to cause rollover of the rest of the combination. If a vehicle has a large amount of rearward amplification, the driver may be able to steer the power unit around the immediate obstacle without approaching the rollover limit of the tractor, but the trailing units may swing out of the path of the tractor -- in a "crack the whip" fashion -- thereby going off the road or into an adjacent lane and/or rolling over due to the high lateral acceleration generated during the "correction phase" of the maneuver. (see Figure 54.)

Figure 54. Lateral Acceleration in an Obstacle Avoidance Maneuver Defining the Amplification Ratio.



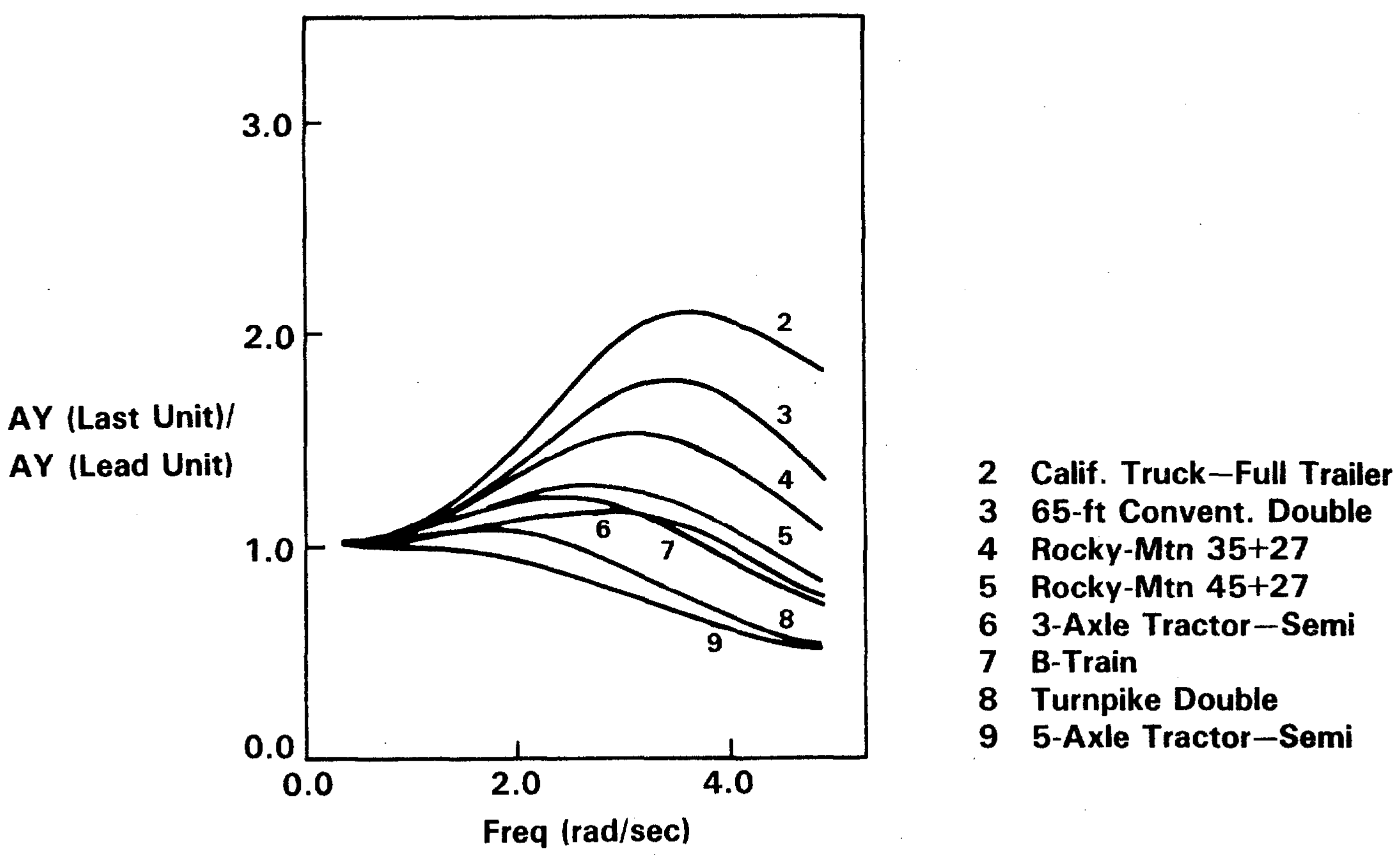
In recent years, studies of rearward amplification have increased. This is a result of increasing economic pressure to improve the productivity and energy efficiency of trucking in the U.S. through changes to the size, weight and configurational restrictions. These analyses have quantified the relative performance of various combination vehicles in the context of their response to rapid steering inputs. Both linear models, for investigating the frequency sensitivity of the phenomenon, and nonlinear models to quantify the transient responses involving large levels of lateral load transfer have been used.

Steering inputs have been studied over a broad range of nominal frequencies, ranging from long period inputs associated with normal lane changing, to the relatively short period steering reversals which might be applied in an emergency obstacle avoidance maneuver. Shown in Figure 55 are the frequency responses obtained at a forward velocity of 55 mph for typical North American vehicle configurations now in use today in the United States or Canada or are likely to be used in the future depending on truck size and weight policy changes. It can bee seen that at very low frequencies, representing mild maneuvers such as a normal lane change or passing attempt, the amplification ratio is equal to unity (i.e., the response of the rearmost vehicle element is identical in amplitude to that of the tractor). As the input frequency approaches 3 to 4 rad/sec most of the vehicle combinations begin to show an amplified rear trailer response.

For practical purposes, it is generally recognized that human steering input capability effectively limits the upper range of frequencies to approximately 3.00 to 3.25 rad/sec. (i.e., steer inputs having approximately 2 second nominal period). Amplification ratios significantly greater than 1.0 can be attained in this range of steering frequencies.

Data plotted in Figure 55 show that the level of amplification is larger for the multiply/articulated vehicles which are shortest in overall length (and which thus employ the shorter individual trailer lengths). Research has shown that the amplification ratio decreases with increasing length of individual trailers and increases with increasing number of units in the combination.

Figure 55. Influence of Steer Input Frequency on Rearward Amplification (For the Case of Steady State Steering Oscillation)

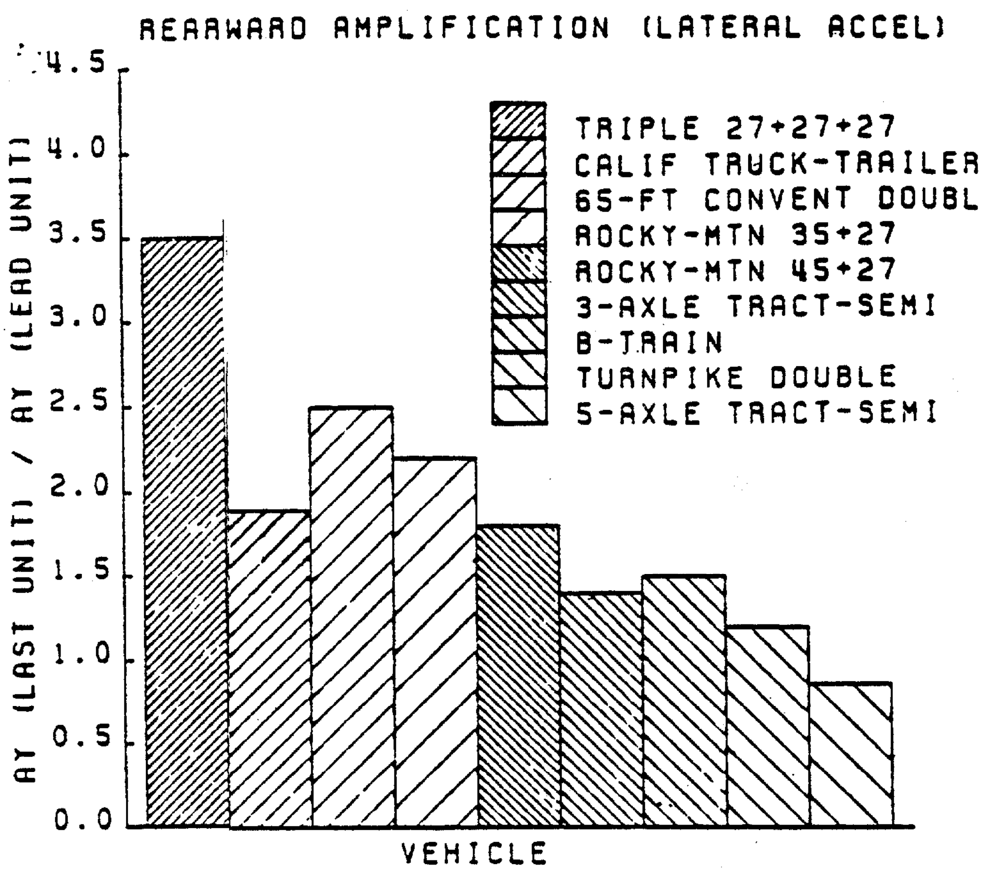


Frequency response analyses provide a "first cut" at distinguishing among vehicle configurations with regard to their amplification characteristics. Nonlinear models have been used to provide a characterization of vehicle response in an emergency obstacle avoidance maneuver. The obstacle avoidance maneuver was intended to illustrate the comparative magnitude of the amplification behavior of the selected vehicles while the frequency response analysis was intended to illustrate the spectrum of frequency sensitivities.

The overall results from the nonlinear simulation are summarized in the bar charts shown in Figures 56 and 57. Figure 56 shows the rearward amplification exhibited by each of the vehicles for the case involving a peak lateral acceleration level of 0.3 g at the rearmost trailer. The amplification measure was calculated, in these data, using the 0.3 g peak lateral acceleration value at the last trailer radioed to the nominal lateral acceleration amplitude associated with the path layout. The path itself then defines the "severity" of the maneuver.

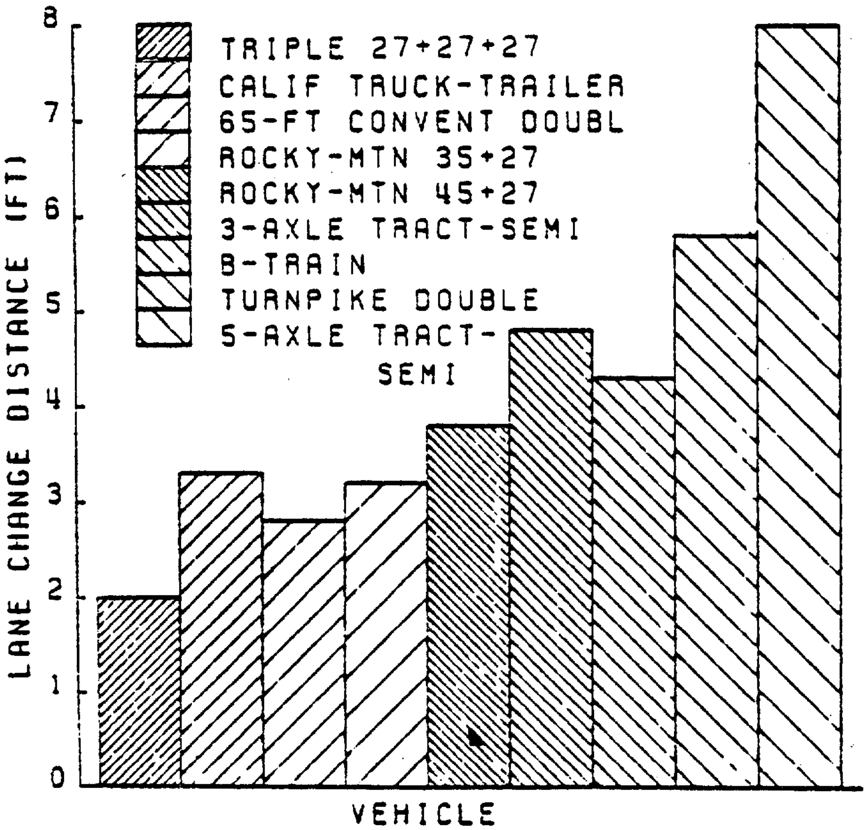
It can be seen in Figure 56 that lateral acceleration levels are registered which are both higher and lower than the values that were obtained in the frequency response analysis. These differences are attributable to fundamental distinctions between the transient and steady state response of dynamic systems.

Figure 56. Rearward Amplification Levels Exhibited in Obstacle Avoidance Maneuver



Another means of characterizing the relative magnitude of the amplification responses is presented in Figure 57. This Figure shows the value of the total lateral displacement of the path at which the rearmost trailer produces a 0.3 g peak value of lateral acceleration. Higher values of this lateral displacement measure are desirable since they imply that the driver of such vehicles could "get away with" maneuvering to clear much larger obstacles without risking rollover of the rearmost trailer. In this sense, the high amplification vehicles would be said to be "less forgiving", thus effectively reducing the safe maneuvering options of the driver.

Figure 57. Lateral Displacement Level Achieved by Each Vehicle Before Exhibiting a 0.3 g Peak in the Last Trailer's Response.



Having illustrated that significant differences exist in the amplification behavior of contemporary U.S. vehicles, it remains to connect amplification levels to an increased likelihood of rollover accident involvements. The projection of accident involvement is inherently tenuous because of the large number of variables which influence accident causation. In certain cases, vehicle configurations such as triples have been admitted into service only under special maintenance and driver selection agreements and only on certain designated routes -- and the safety records have been reasonably good. Thus it cannot be said, categorically, that vehicles with high amplification ratios will necessarily do poorly in the field.

Perhaps more general direction can be obtained, however, when vehicles are considered for general freight service and are to be driven by the general truck driving population. All other accident causation factors being equal, it is expected that vehicles having a greater degree of rearward amplification level will be over-involved in accidents in which the rear trailer rolls by itself.

Rearward amplification is one vehicle property which is potentially identifiable as a causative factor in the accident record. The physics of the problem suggest that accidents in which the rear trailer rolls over and all other units of the vehicle remain standing have a very high likelihood of being associated with rearward amplification. In the cases for which accident data provide a substantive assessment, this relationship has been nominally confirmed.

In an attempt to quantify the safety importance of rearward amplification, Heath (1981), of the California Highway Patrol, analyzed 117 combination tank truck accidents that occurred between February 1, 1980 and January 31, 1981 on highways under their jurisdiction. Special attention was directed towards the occurrence of rear trailer rollover accidents. He found that overturning was the most common type of combination tank truck injury and property damage accident (see Table 46). The proportion of overturns for tank trucks was three times that recorded for all other trucks in fatal and injury accidents and six times in property damage accidents.

Table 46. Combination-Unit Truck Accidents in California by Type of Collision

Type of Collision	Fatal and Injury Accidents				Property Damage Accidents			
	Tank Trucks		Other Trucks		Tank Trucks		Other Trucks	
	No.	%	No.	%	No.	%	No.	%
Head-on	7	12	58	3	0	0	27	1
Sideswipe	9	15	437	25	14	25	1385	40
Rear End	11	18	603	34	6	11	660	19
Broadside	10	16	224	13	5	9	235	7
Hit Object	10	16	254	14	7	12	627	18
Overturned	13	21	117	7	22	39	212	6
Auto/ Pedestrian	0	0	18	1	0	0	0	0
Other	1	2	51	3	2	4	302	9
Total	61	100	1762	100	56	100	3448	100

SOURCE: Heath (1981)

Fifty nine percent of the tank truck accidents involved overturns. Tractors pulling semitrailers overturned in 48 percent of their accidents, trucks with trailers in 60 percent of their accidents, and doubles in 70 percent of their accidents (see Table 47)

In overturn accidents involving trucks with trailers, the trailer overturned in 45 percent of the cases. In overturn accidents involving doubles, the last trailer or semitrailer only overturned in two thirds of the cases. It was noted that the majority of these accidents involved filled tanks such that sloshing of the fluid load was not a factor.

Table 47. Types of Tank Trucks in Overturn Accidents in California

Type of Tank Truck	Overturn Accidents No.	%	All Accidents No.	%	Ratio of Overturns/All
Truck and Trailer	40	58	67	51	.60
Tractor and Semitrailer	13	19	27	21	.48
Tractor and 2 Trailers	16	23	23	17	.70
Total	69	100	117	100	.59

SOURCE: Heath (1981)

The accident experiences of the Consolidated Freightways fleet, revealed in litigation, tended to show that while doubles do not have many more accidents than tractor-semitrailer combinations, many more of the doubles accidents involve rollovers and some 60 percent of the doubles rollover accidents are rear-trailer-only type. These data indicate that rearward amplification plays an important roll in the doubles accident picture, tending to increase the cost and severity of the accidents in which these vehicles are involved.

The Highway Safety Research Center of the University of North Carolina, working for the North Carolina Governor's Highway Safety Programs studied the potential safety issues related to the use of doubles trailers on North Carolina roadways. North Carolina has experienced very few doubles crashes since the Surface Transportation Assistance Act of 1982 went into effect. Between December 20, 1983 and February 15, 1986, 67 accidents occurred in North Carolina involving doubles. This compares with typically 4500 - 5000 crashes annually in that state involving tractor-semitrailer combinations. However, in 17 of these accidents (25 percent) the rear-trailer unhooked during the crash. Most of the trailer disconnects appear to be initiated by sudden steering or cornering maneuvers.

Steering Control Issues Below The Static Rollover Threshold

The dynamic behavior of highway vehicles derives primarily from mechanical properties of the pneumatic tire. Specifically, the ability of the pneumatic tire to distort laterally causes motor vehicles to exhibit a turn response to steering (i.e., a curved path) whose magnitude is speed dependent and which may either grow or decrease as speed is increased. In the case of the passenger car, the rate of growth (or decrease) of path curvature with speed (per unit steering input) tends to be independent of the forces (acting at tire/road contact) which cause the vehicle to traverse a curved path, provided these forces are less than 0.3 times the weight of the car. In the case of the medium/heavy truck, the relationship between path curvature and steering input tends to become nonlinear at side force levels which are less than one tenth the weight of the truck. Even more important than this limited range of linear behavior, is the general tendency of heavy trucks to lose their initial stable response quality and become a potentially unstable dynamic system. This occurs when the side forces acting on the tires increase to levels sufficiently high to cause the velocity to respond nonlinearly but below the levels required to cause a rollover. If the speed of the truck is high enough, a driver steering action will cause path curvature to increase in a divergent manner, provided the driver takes no follow-up action to stabilize the vehicle's path. Even when the speed is below the speed at which the truck becomes unstable, a driver has the difficult task of controlling a mechanical system which is characterized by long response times as well as large levels of turning response per unit displacement of the steering wheel.

The extent to which these characteristics influence a driver's ability to control his truck, is not known at this time. The experience derived from the design and development of passenger cars does not help, since passenger cars tend to behave in a linear manner over the range of maneuvering levels encompassed in normal, routine driving. Additionally, passenger cars, which are intended to be driven by ordinary drivers, are carefully designed to lose their ability to turn at higher acceleration levels before stability is lost and a spinout occurs.

The question arises as to whether this propensity has any bearing on the extent to which truck drivers lose control of their vehicles. The accident record does not indicate whether truck drivers experience control difficulties in excess of the difficulties encountered by the passenger car driving population. Nevertheless, it is reasonable to hypothesize that, since control problems arise primarily when the truck is required to perform a maneuver that is more severe than that experienced in everyday, routine driving, drivers do not have adequate opportunity to learn how to react properly under these conditions. This suggests that the steering controllability characteristics of heavy trucks may be constitute a factor in the accident-causation process.

The physics of truck response to steering is well understood, but the extent to which truck directional control and stability makes unreasonable demands upon the driver skill is not. Research is needed primarily to address the human factors aspects of the problem, i.e., to identify the reasonable and practicable countermeasures necessary to upgrade the controllability performance of trucks (or tractor-trailer combination). Previous research shows that some corrective steps apply to the design and construction of power units, whereas other steps apply to operational and maintenance practices.

Oscillatory Behavior of Multiply-Articulated Combination-Unit Trucks

In addition to the aspects of vehicle design and operation which establish whether a truck will respond to steering inputs in a stable manner, articulated vehicles can exhibit oscillatory behavior when simply travelling in a straight line. This behavior can be caused by slight steering actions or by other kinds of road or wind disturbances. Typically, it manifests itself as rear trailer side-to-side oscillation.

Prior research has, in large measure, identified the design and operating conditions which lead to either lightly damped or unstable oscillations. In general, information is available on how (1) the geometry of the vehicle system (namely, the location of axles and articulation hinges with respect to the various mass centers), (2) the mechanics of tires and steering mechanisms, and (3) vehicle speed influence the damping or stability of the individual oscillatory motions. For example, studies have shown that design features which promote good tracking at very low speed are likely to cause the oscillatory motions at higher speed to be more lightly damped. Further, for each trailer and articulation hinge added to the vehicle system, the more lightly damped the additional oscillatory mode of motion becomes, increasing the potential for a divergent oscillation as speed is further increased.

Oscillatory behavior places an upper limit on the number of articulated mass units which can be incorporated into longer combination vehicles. It is most common when payloads are improperly distributed in "doubles" or "triples" combinations. Although the oscillations may not be large enough to cause loss-of-control,they may result in trailing units encroaching on other travel lanes thereby intimidating other motorists.

Oscillatory phenomena only occur with the use of doubles or triples combinations (or perhaps with a truck-full-trailer trailer combination). No data exist to demonstrate it causes accidents. On the other hand, there is evidence that the response of trailing units to rapid steering maneuvers can result in the rearmost unit experiencing an acceleration sufficient to roll this unit over.

The California Department of Transportation (Caltrans) recently conducted an over-the-road operational test of three longer combination vehicles -- triple trailers (three 28-foot trailers), Rocky Mountain doubles (one 48-foot semitrailer plus one 28-foot trailer) and turnpike doubles (two 48-foot trailers). With the triples, Caltrans noted a constant sway in the combination which could create problems in dense traffic conditions.

Recommended Research Plan For Improving Truck Handling And Stability Performance

Of the topics previously discussed, rollover has direct and significant safety consequences and is in need of additional work to translate previous research findings into implementable solutions. Accordingly, a program for further research in this area is proposed.

Rearward amplification is a problem unique to a special class of vehicles (mutiply-articulated, larger combination unit vehicles (LCV's)). Some vehicle design-related changes could be made that would help reduce the likelihood of this occurring. These are close to being implementable now and are discussed herein. Other factors also affect this tendency, however, in many cases, to a greater degree than do vehicle-related factors. These include operational use practices and legislative choices relating to vehicle size, weight, and configuration allowances -- issues beyond the scope of this report.

Problems associated with low speed off-tracking are certainly a concern from a traffic engineering and operations viewpoint, but are not significant from an highway safety viewpoint. Few traffic accidents are likely to be associated with this characteristic of trucks. Those that do occur are likely to be low severity, property-damage-only events. Accordingly, no additional work on this subject is proposed.

High-speed yaw instability, while demonstrable from an engineering viewpoint, is not evident as an accident causal factor. It is not likely to ever be evident in mass accident data files, since when and if it does occur, it is likely to result in the vehicle rolling over. This topic is best addressed in conjunction with efforts to improve truck roll stability.

The oscillatory behavior of multiply-articulated vehicles is also not likely to be a significant highway safety problem due to the highly restrictive use provisions that are typically applied to the operation of these types of vehicles. This issue is best addressed through those types of sanctioning provisions.

Rollover

Rollover is given the highest priority among handling and stabilty related issues because it is well understood and has an obvious direct link to safety. Rollover is easy to identify and observe. It is a vehicle response property that is, in itself, a crash. In addition, test techniques (i.e., the tilt-table method) have been devised and are currently in use to experimentally quantify the static rollover thresholds of medium and heavy trucks. The program to improve the roll stability properties of trucks follows three parallel paths.

One of the paths would be directed towards developing the best methods of gauging the relative roll stability performance of trucks. It would take into account static and dynamic considerations.

Another path would attempt to establish what motion and visual cues drivers sense (or possibly fail to sense) prior to a rollover. This information could help driver training efforts and could possibly result in more of the "good" cues being built into future trucks.

Another path would study in-service trucks to assess how many of them are typically being operated close to their stability limits. This would include studies of truck tires to determine the degree to which their performance properties affect vehicle stability and control. A determination would also be made as to which properties of in-service trucks are most responsible for stability limits being approached. Finally, an assessment would be made of the impacts that would result from design-related changes that might be contemplated to enhance roll stability of future trucks.

The focus of prior work in truck roll stability has been on static phenomena and, specifically, on rollover in a steady turn. Since static stability level is a favored measure for formulation of a practical standard on roll stability, there is a need to examine dynamic phenomena in order to assess the adequacy of a static-only specification. Concerning rollover stimulated by rearward amplification, there is a need to expand the study of rearward amplification to account for the frequency-dependent nature of the rollover response.

The test procedure development portion of the research would initially focus on defining the vehicle properties which determine transient roll response -- i.e., dynamic motions of the payload, vertical excitation at the roadside, transient lateral acceleration inputs, tripping on curbs and other obstructions, etc. Computerized simulation would be used to identify any conflicts posed by the desire for both static and dynamic roll stability. Ranges of design parameters serving to benefit both static and dynamic roll stability would be defined for guiding the formulation of a comprehensive roll stability specification.

The computer simulation of the rearward amplification phenomenon would focus on the frequency ranges in which rearward amplification maximizes and would identify the vehicle properties influencing roll stability under this particularly dynamic condition.

Based on this work, the technical definitions, measurements, test procedures, and other protocols needed to specify a standard could be developed. The most attractive candidate method for measuring the static roll stability of assembled vehicles is the "tilt-table" device. Procedures must also be developed for measuring the properties of each unit in multi-element truck combinations. In this regard, it may be necessary to define a "a reference semitrailer" for use in compliance-testing truck tractors.

Regarding the properties of semitrailers, themselves, it may be that trailer suspensions could be qualified separately such that the diffuse trailer manufacturing industry would only need to address suspension properties and center-of-gravity locations. The test procedures and pass/fail levels constituting a model standard would be developed and applied to a number of representative vehicles to demonstrate and refine the compliance test process.

Turning to the driver-related studies, experiments in which real truck drivers would operate differing trucks near the rollover limit (with protective devices) would indicate other aspects of vehicle design which might aggravate or benefit the driver's ability to sense the proximity to rollover.

The ability to predictably control a vehicle's path is an obvious prerequisite to its safe operation. Some medium/heavy trucks are relatively easy to control under ordinary driving circumstances, but may become unusually tricky to handle if emergency maneuvers are attempted. Where this is the case, drivers may find it difficult to successfully perform evasive actions to avoid unanticipated obstacles and/or resolve traffic conflicts.

Limited knowledge exists relative to how driver steering control actions are affected by the steering response ("feel") characteristics of trucks. To obtain a fundamental understanding of how drivers respond to trucks with differing handling and "feel" qualities, a study of truck drivers would be necessary. Research on human factors, as well as control engineering research, is needed. Based on research on passenger car driving, some of the driver factors to be considered include (1) driver sensitivities to path-keeping errors, (2) the previews that drivers use in planning and adjusting their control actions, and (3) the bandwidths or time periods they need to be able to control vehicles with sufficient accuracy for the space available in traffic. All this information would be incorporated into an enhanced driver/vehicle model which could be used to assess alternative designs.

Using the results from the truck driver studies, the influences of the steering performance properties of trucks on the abilities of drivers to control the truck safely could be empirically validated. It is anticipated that a group of truck drivers with a wide, yet representative, range of driver skills would be utilized to study the influence of changes in vehicle properties -- such as level of steering gain, lateral and rotational response times, etc., on the driver factors considered earlier.

Since steering controllability depends mainly on the characteristics of the truck or tractor and only slightly on the units being towed, describing the distribution of steering controllability properties existing in the U.S. trucking fleet would focus on determining the loads carried by the towing unit's tires, the type and condition of tires employed, the geometric layouts, and the mass distribution of the towing units. Understanding the distribution of steering controllability properties would allow definition of performance bands characterizing poor, typical, and good performance over the expected ranges of driver control capabilities. The magnitude of the safety problem would be determined by the number of vehicles projected to have especially poor performance.

The core portion of the rollover research program would be a carefully planned set of driver/vehicle experiments in which maneuvering conditions approaching rollover are involved. A sample of real truck drivers would be enlisted to drive in such experiments, with the test exercise designed to address the crucial items of driver instruction, practice, motivation, feedback, safety protection, etc. Vehicles incorporating differing "feedback" characteristics would be employed in an attempt to identify those characteristics which help the driver anticipate his vehicle's rollover limit.

In the case of rearward amplification, the study would focus on the driver's steering control of doubles combinations. Situations requiring evasive steering maneuvers would be contrived and the actions of the driver observed in order to put a firmer basis upon the open-loop study of rearward amplification.

One outcome of the planned research would be a better definition of what the driver can and cannot be expected to do in avoiding rollover. Another outcome would be the identification of those vehicle properties which are instrumental in providing beneficial feedback to the driver. Such feedback properties could be promoted in improved vehicle design practice or, conceivably, included as a requirement in a safety standard.

Finally, the vehicle-related studies would follow several concurrent paths. First, a sampled inventory of the U.S. trucking fleet would be done to estimate the distribution of roll stability properties across the fleet. A preliminary link has been made between rollover probability and static rollover threshold. In addition, Australian studies have shown that existing suspension systems/vehicles in that country have low rollover thresholds. Therefore, a need exists to describe the distribution of roll stability levels prevailing in the U.S. trucking fleet, given the way trucks are equipped and loaded in normal service. Knowing how roll stability levels are distributed across the population will establish, for example, whether dramatically low "outliers" exist and will enable projection of the number of vehicles which would be affected by the setting of a certain compliance level.

Now that tilt-tables are available in both Canada and the U.S., this type of measurement facility would be most appropriate for obtaining a meaningful sample of static rollover threshold data through measurement of all combinations of truck and trailer suspension systems available in the U.S. -- an analogous study to that performed by Sweetman and Mai in Australia.

Simultaneously, a field experiment in which real trucks are instrumented with a data logging system to monitor the way they are driven would be initiated. The experiment would be conducted on differing trucks with differing drivers in operations across the U.S. to establish the "demands" which are made on vehicle roll stability from day-to-day. A probability analysis of the results would project the relationship between stability, level, and the likelihood of rollover, given the demands which exist.

A data logging instrumentation system would be assembled and a procedure for its use would be developed and demonstrated in a pilot exercise. Subsequently, a sample of commercial vehicle operations will be selected for the collection of data using the logging system in normal trucking service. Data collection would cover differing vehicle configurations, drivers, types of trucking service, and regions of the country. Recordings of the measured acceleration responses will be retrieved from the on-board instruments and returned to the laboratory for computerized analysis. The data will be analyzed to predict the likelihood that acceleration demand will exceed vehicle performance limits in each of the respective modes of loss-of-control. This "likelihood" prediction will relate differing performance limits to the probability of control loss, thereby connecting each vehicle performance area to a corresponding aspect of accident production.

In addition to the data indicating the probability distribution of acceleration demands which truck drivers impose upon their vehicles in everyday service, ancillary data accompanying the acceleration recordings would be obtained to define the operating conditions which influence these distributions. These data could then be used to predict the likelihood of rollover (given the value of the vehicle's inherent rollover threshold and/or the likelihood of a rear trailer rollover due to rearward amplification in a multi-unit vehicle combination). In the case of rearward amplification, the analysis would require treatment of both amplitude and frequency information from the in-vehicle recordings.

There is a need to better understand the effects of tire performance on the stability and control properties of trucks. Ultimately, tires transmit all the driving and braking torque and develop the cornering and directional stability essential to the performance of highway vehicles. Research has indicated that truck tires are generally deficient compared to car tires in traction, especially on wet pavements.

Accident studies have suggested that trucks may, indeed, be frequently over-involved in loss-of-control situations on wet/slippery roadways. Thus, there is justification for more closely examining the traction problems experienced with truck tires as a potentially important means of improving overall truck controllability. Few engineering evaluations of traction mechanics have been made. A definitive study of truck tire traction performance is needed.

Studies to upgrade the present understanding of truck tire traction performance would include testing of a large sample of truck tire types to determine the ranges of combined longitudinal and lateral traction performance available from present truck tires. In addition, an evaluation of the traction performance of service-worn tires in conjunction with a tread depth survey to quantify the distribution of state of wear typical of the U.S. truck fleet would be completed. Finally, this portion of the research would identify the operating conditions under which trucks may suffer control problems due to traction deficiencies.

Deficiencies in the traction performance of truck tires may call for both innovative changes in tire design as well as simply a greater level of attentiveness to usage on the part of the trucking industry. These studies hopefully would provide the impetus and direction to spur industry research seeking to improve truck tire traction performance. The government research would serve to clarify the options and guide the attainment of solutions.

The last set of vehicle-related studies would examine a set of candidate approaches toward improving truck roll stability for technical feasibility and practicality of implementation.

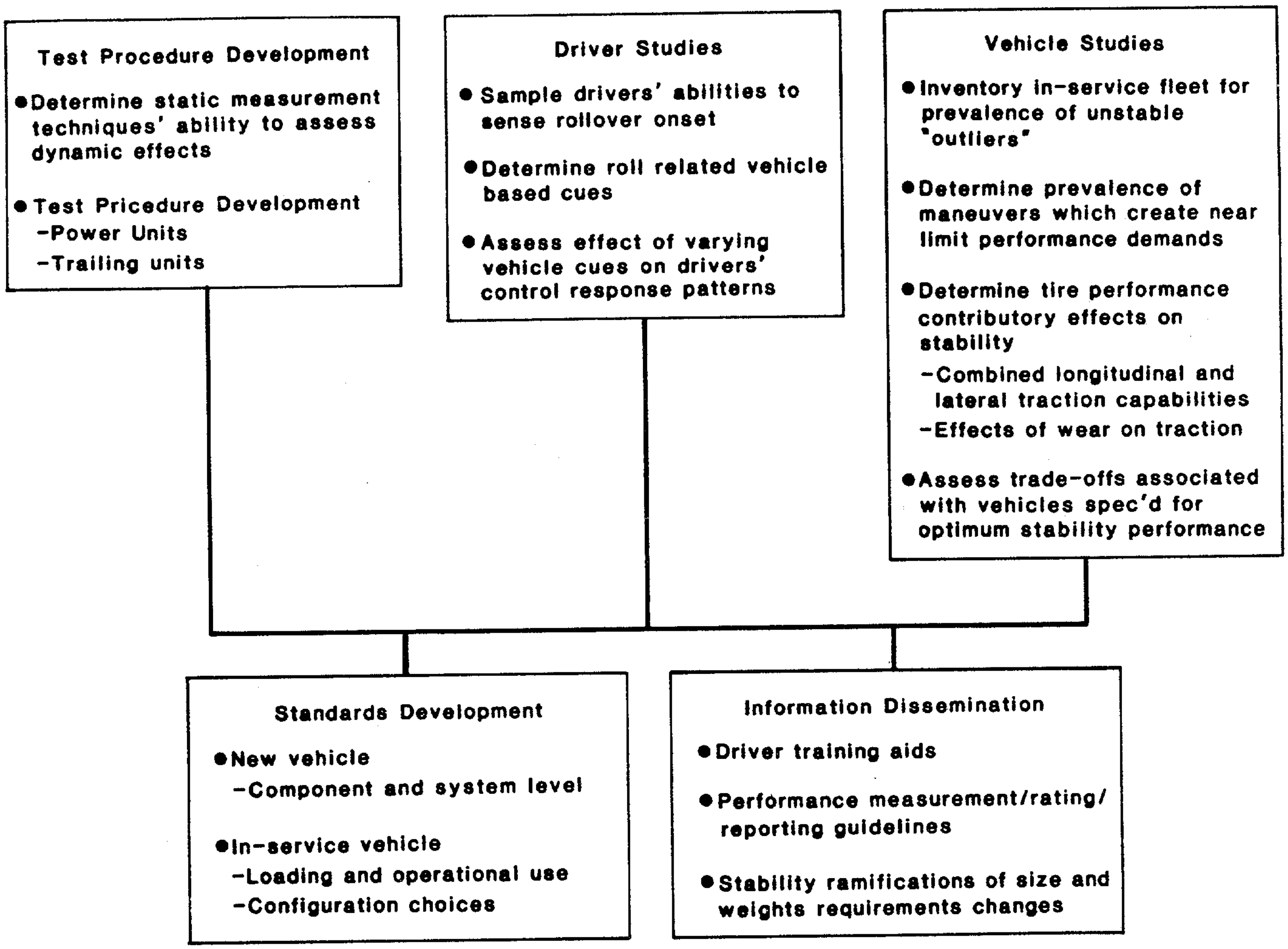
Candidates for improving roll stability, as well as the sensory feedback properties of vehicles, would be developed, based on the results of all of the research preceding this stage. The candidate countermeasures would be evaluated, first, by means of studying field experience gained with any examples of such hardware that may be in current service. Safety effectiveness estimates would be made with the aid of engineering analyses and the generalized models of accident probability developed in previous projects. The practicality of countermeasures which have no precedence in the field may require field trials of prototypes and assessments of the supportive technology for implementation. This study would conclude by identifying each viable countermeasure, together with the data which would enable a cost/benefit study.

The overall roll stability enhancement research program is shown in Figure 58.

Rearward Amplification

Of the trailing fidelity issues, rearward amplification is judged to be the most important because it is known to contribute to multi-articulated vehicle rollovers. Rearward amplification is strongly related to the nature of the trailer-to-trailer hitching mechanism(s).

Figure 58. Truck Roll Stability Enhancement Research Program

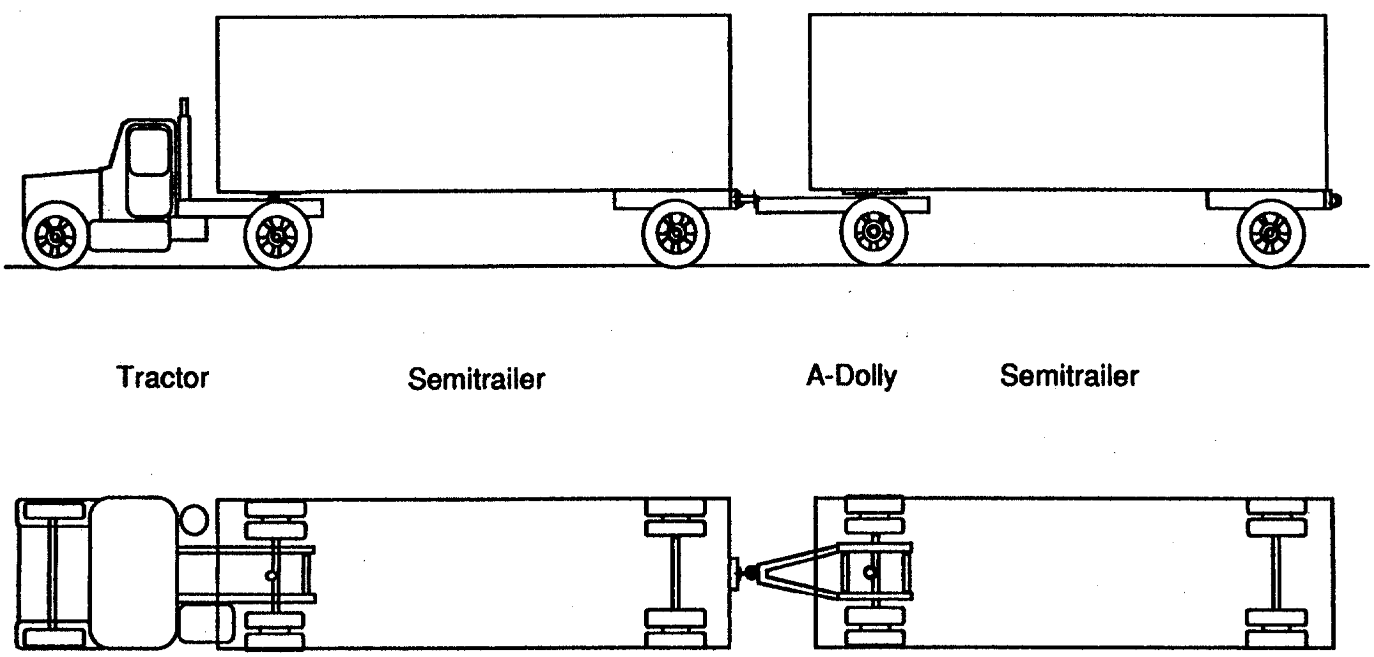


The most common multi-articulated vehicle in operation in the U.S. is a tractor-semitrailer pulling one or more full trailers. Each full trailer, in this case, consists of a semitrailer whose forward end is supported by a dolly which 1) articulates in yaw relative to the semitrailer, 2) is connected to the towing unit by a single pintle hitch, and 3) has one or more axles which are non-steering relative to the dolly frame. This configuration, shown in Figure 59, is commonly referred to as an A-train.

While the A-train meets the primary need of providing a large-volume vehicle which can be maneuvered relatively easily at low speed, it is less stable at highway speed than a conventional tractor semitrailer and has comparatively poor rearward amplification performance. Recent research has shown that the rearward amplification factors of 2 to 2.5, which is characteristic of typical doubles, can be readily reduced to the order of 1.5 with improved dolly designs.

These analyses have also shown that, for the conventional multi-trailer vehicle, the most important vehicle properties relating to rearward amplification are (1) tire cornering stiffness, (2) vehicle wheelbase, and (3) pintle hitch location in the towing trailer. Stiffer tires, longer wheelbases, and more forward locations for the pintle hitch all reduce rearward amplification. (Somewhat surprisingly, the tow-bar length of full trailers is now known to be relatively unimportant.) Thus, doubles, composed of two short trailers, generally show high, overall rearward amplification, as do trucks towing short, full trailers, particularly when the truck has a large rear overhang to the pintle hitch. Addition of other full trailers, as in triples, further aggravates the problem. Since "tuning" among the various elements of the vehicle is involved, vehicles with multiple, identical trailers can generally be expected to have greater amplification.

Figure 59. An A-train is Composed of a Tractor-Semitrailer Towing One or More Full Trailers Made of an A-dolly and Semitrailer.



In recent years, attempts have been made to introduce new design features which would mitigate rearward amplification. Most of this development is being conducted in Canada and Europe.

The most basic innovation was the introduction of the B-train (see Figure 60). In this vehicle, the pintle hook articulation joint is eliminated, and the vertical support and fifth wheel articulation functions of the dolly are incorporated into the rear of the leading trailer. Rearward amplification is greatly reduced, but a number of practical problems limit the application of this concept only to doubles operations with "married pairs" (i.e., trailers are always used together and are not interchangeable) and for trailer types that do not need to be unloaded from the rear.

A more popular variation of the design approach uses a B-dolly to make up a C-train (see Figure 61). The B-dolly uses two pintle hitches to eliminate dolly steering and usually incorporates some form of "self-steering" axle which allow the dolly tires to steer by caster (but with some centering mechanism applied). The goal is to allow enough free steering to reduce tire wear and objectionable frame stresses, while supplying enough steering resistance to provide dynamic stability.

Other innovative dolly concepts have seen limited use. These include the "four-bar link dolly," the "linked articulation concept," and a controlled steering dolly.

The University of Michigan Transportation Research Institute, under contract to the FHWA, has evaluated the performance characteristics of these hitching concepts analytically, and is currently conducting full-scale vehicle tests of the four most promising concepts -- an asymmetric 4-bar linkage dolly, a linked articulation dolly, a steerable axle B-dolly, and a prototype dolly which attempts to combine the good features of the other dollies.

All of these innovative hitching concepts can improve dynamic performance, but each has drawbacks which tend to severely restrict their use in the United States.

The main thrust of the current work is to improve the "rearward amplification" of the doubles vehicle and the "dynamic roll stability limit" of the last trailer without substantially degrading performance in the areas of low and high-speed off-tracking and directional stability in braking maneuvers.

The A-dolly is a remarkably simple, inexpensive, light, low maintenance, practical device with no drawbacks other than that it significantly contributes to the rearward amplification phenomenon. Compared to it, each of the other available dolly concepts exacts penalties of initial cost, weight, maintenance, and operational difficulties.

Figure 60. A B-train is Composed of a Tractor Towing Two or More Semitrailers. The Towing Trailers Have an Extended Frame with 5th Wheel For Attaching the Next Trailer Made of a B-dolly and Semitrailer.

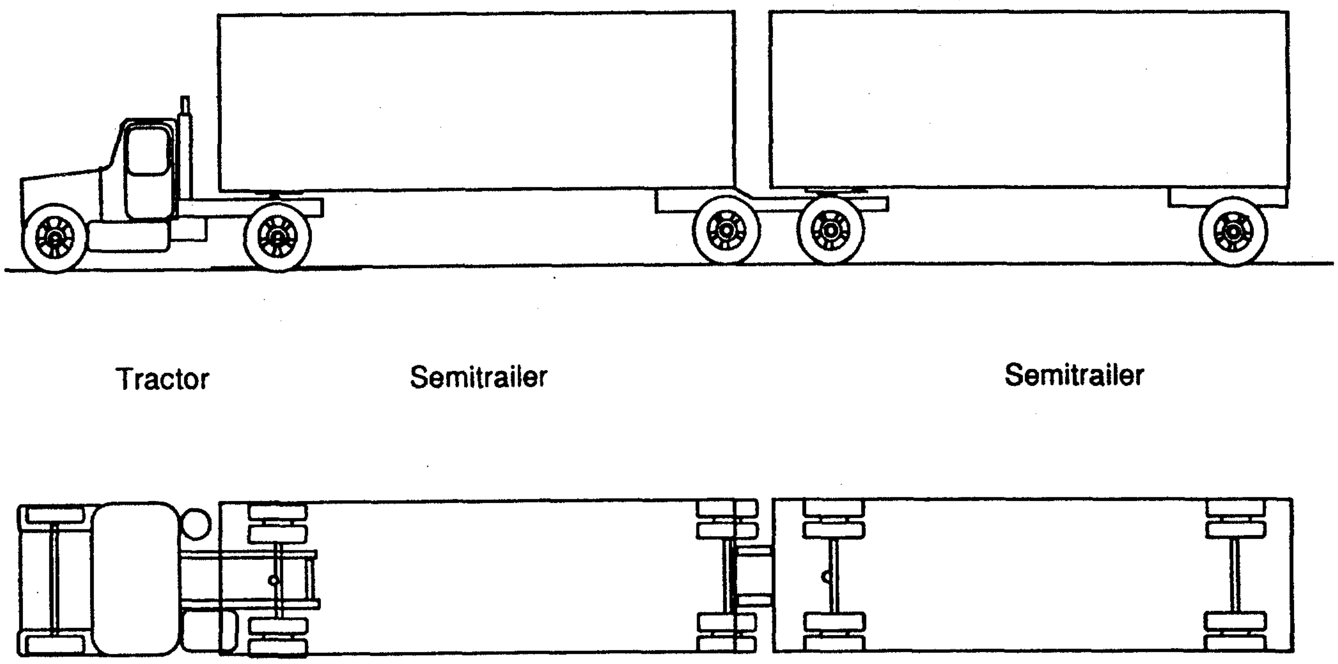
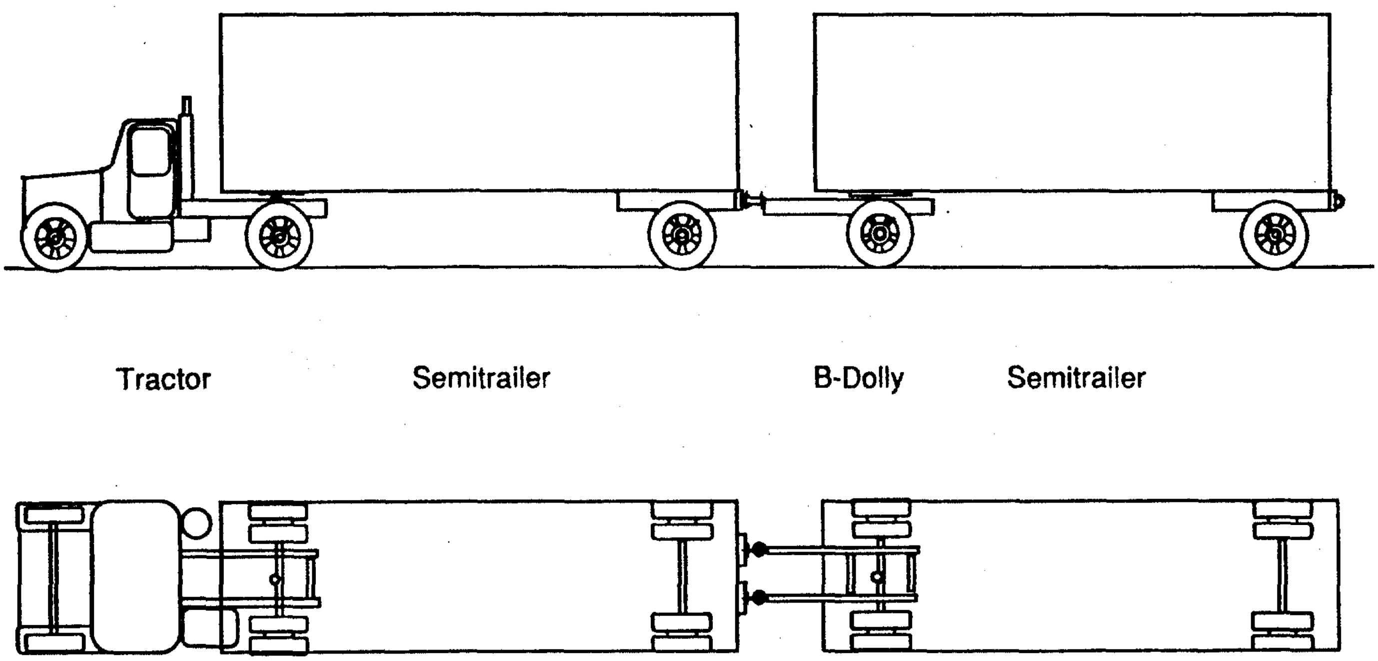


Figure 61. A C-train is Composed of a Tractor-Semitrailer Towing One or More Full Trailers Made of a B-dolly and Semitrailer



It appears that technical solutions are available for the rearward amplification problem. However, implementation strategies are not readily as clear. Although an in-fleet demonstration program of optimum hitching arrangements for multi-articulated vehicles -- i.e., minimization of rearward amplification tendencies as well as cost, weight, maintenance and operation impacts -- would help promote these concepts, the most likely method for obtaining their widespread use would be as quid pro quo if changes in the size and weight laws are made in the future.

Low-Speed Off-Tracking

Low speed off-tracking is not considered to be a significant highway safety problem per se, but rather a traffic operations issue. It should be noted that in many cases the current tractor/48 ft semitrailer combination appears to have taxed the geometric allowances of the road system to its limits.

High-Speed Off-Tracking

Regarding transient, high-speed off-tracking behavior, i.e., abruptly entering a curve at high speed, recent observations made during full-scale vehicle testing indicate that the actual outboard off-tracking of vehicles is much greater than the steady-state excursions that have been addressed previously. This phenomenon might render high-speed off-tracking a more important safety issue than earlier believed, due to either the trailer intruding into adjacent traffic lanes (or multi-lane entrance exit ramps, e.g., high-speed merges of two interstate highways) or excursions onto the shoulder, either of which possibly resulting in a "tripped" rollover.

Current mass accident data do not provide the detail necessary to assess the safety significance of high-speed off-tracking. Comparison of the acceleration demands of trucks in actual revenue service (see data logging study under rollover) with data on the statistical distribution of truck wheel paths occurring on high-speed curved roadways and ramps would enable the conduct of probability analysis for predicting accident rates due to high-speed off-tracking.

SECTION 5. MEDIUM AND HEAVY TRUCK CRASH PERFORMANCE - TRUCK AGGRESSIVITY

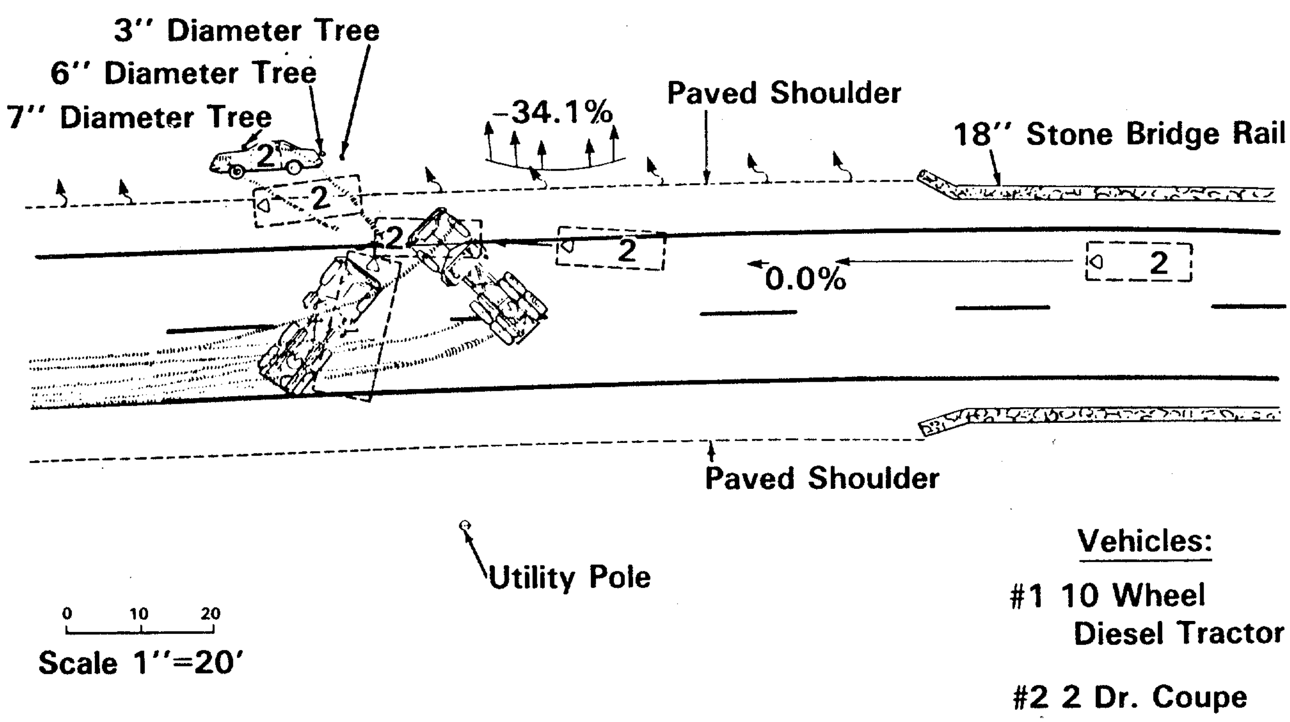
INTRODUCTION

On March 8, 1986, a three-axle truck tractor was operating bobtail on a two lane road in Prince Georges County, Maryland. It was travelling in a traffic stream which was moving at 45-55 mph. All the vehicles in this traffic stream were speeding, -- not an uncommon practice on this stretch of straight road with few intersections. It was 11:00 A.M. and the weather was clear. Two other vehicles were travelling along the shoulder of the roadway, at a much slower speed, their drivers struggling to keep on their roofs sheets of plywood which were tied to the vehicles. Traffic was passing the two vehicles.

The shoulder of the road narrowed on a stone bridge. When the two slow-moving vehicles reached the bridge, they both moved to their left onto the roadway. This forced the traffic stream that was following to greatly slow down in a chain reaction manner. The truck tractor was several vehicles back in the stream.

Apparently, by the time the truck driver saw brake lights, he was forced to attempt a fairly "hard" stop. Operating bobtail at this speed and with no front wheel brakes, the tractor drive axles immediately locked up as the vehicle skidded for more than 300 feet attempting to avoid rear-ending the slowing traffic stream. Towards the end of this long skid, the tractor yawed to its left with its front end over the centerline of the roadway, ending up almost perpendicular to the direction of travel. The accident scene is shown in Figure 62.

Figure 62. Accident Schematic



A passenger car travelling in the opposite direction at approximately 45 mph came upon the tractor unexpectedly and had only enough time to attempt a slight accident-avoidance turning maneuver to its right. It did not fully execute this maneuver and hit the bumper of the tractor, almost parallel to the face of the truck bumper, in a glancing-blow type of collision. The estimated collision delta-V for the car was 30 mph.

The truck's bumper first contacted the car in the area of the front fender at a height slightly above the headlights. The rest of the contact down the side of the driver's side of the car occurred at a height approximately equal to that of the outside rear-view mirror. The car driver was using his seat/shoulder belts, but this mattered little as the side of the car sustained significant intrusion damage. The lateral force imparted to the car caused the driver's head to contact the side roof, killing him almost instantly. The car subsequently skidded to its right and quarter-turn rolled. The truck driver was not injured. The damaged car and truck are shown in Figures 63 and 64 below.

Figure 63.

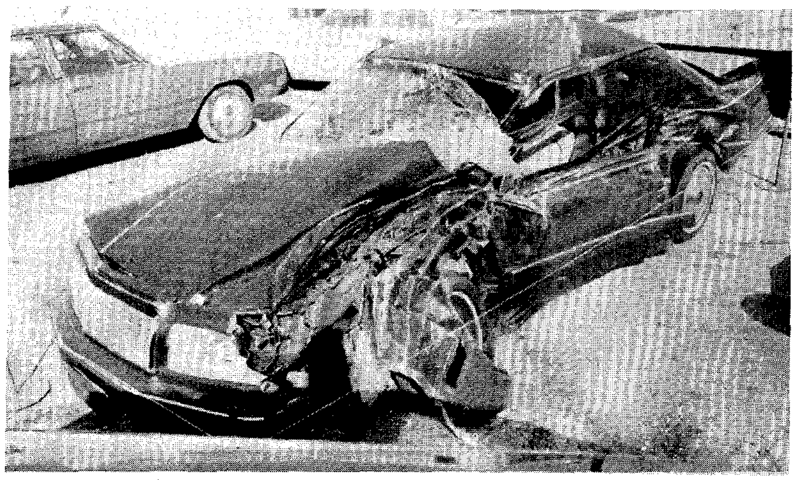
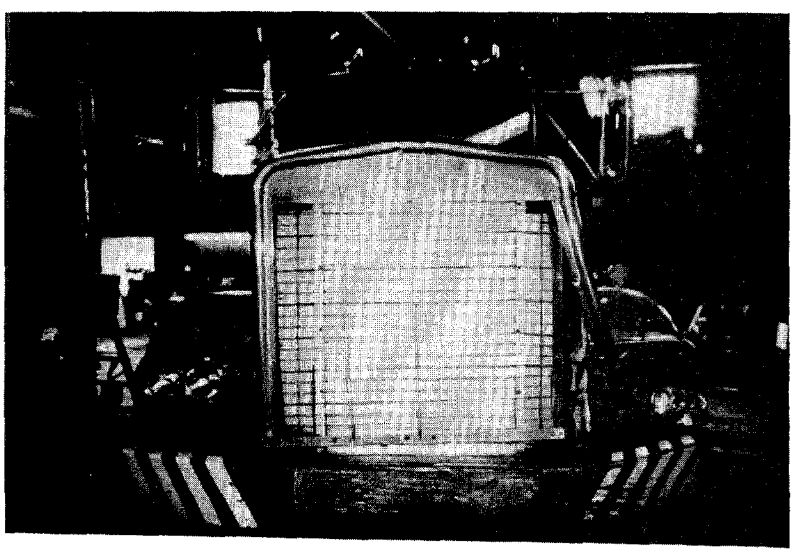


Figure 64.



Aside from the many factors which caused this collision in the first place, this case graphically demonstrates the lethality of truck/car collisions. When any two vehicles of dissimilar size collide with each other, the larger of the two vehicles typically inflicts much more damage and injury trauma than it sustains. In this case, the larger vehicle is said to be more "aggressive" relative to the smaller vehicle. Motorcycle collisions with almost any other vehicle, passenger car/pick-up truck, van and certainly passenger car/medium, heavy truck collisions fit in this category.

This section deals with the results of medium and heavy truck collisions with other vehicle types, all of which are smaller than medium and heavy trucks. In these collisions, the truck's "aggressivity" occurs for two principal reasons: geometric aggressivity, or the fact that the physical shapes of the two vehicles, particularly the front end of trucks, do not match each other; and mass aggressivity, or the difference in weight between the two vehicles.

It is widely believed that little can be done about truck aggressivity because the mass differential in most collisions is so large and because nothing can be done about this, short of segregating trucks from other vehicles. This section will discuss why this may not be totally true, since a significant portion of the problem arises from geometric aggressivity, which the case above demonstrates, and for which practical improvements may be possible.

EXTENT AND SCOPE OF THE ISSUE

Collisions between heavy trucks and smaller vehicles, primarily cars, result in predictably serious consequences for the occupants of the smaller vehicle. Using Texas as an example, collisions of this type result in car driver fatalities 7.5 times as often as they do when cars collide with each other (see Table 48.)

Table 48. Trauma Outcomes Among Drivers of Cars Involved in Various Types of Crashes

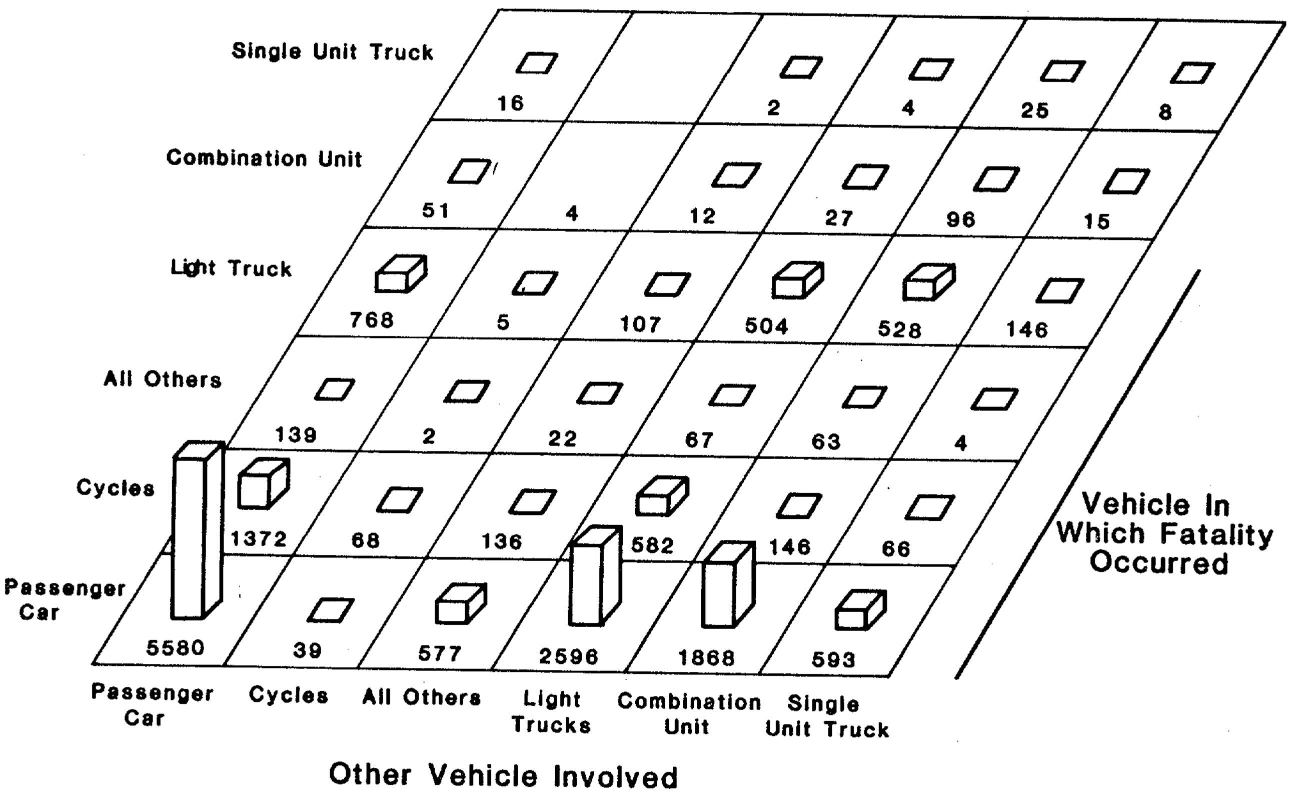
Crash Type	Trauma Outcome		
	Fatal	Injury	No Injury
Collision between a car and another car	1,598 (0.2%)	70,672 (7.1%)	922,489 (92.7%)
Single-vehicle car crash*	1,160 (1.1%)	25,250 (24.6%)	76,294 (74.3%)
Collision between cars and medium/ heavy trucks	346 (1.5%)	2,996 (12.9%)	19,795 (85.6%)

SOURCE: Texas, 1981-1983

* Single-vehicle accidents include collisions with fixed objects, loss-of-control, etc.

The consequences of this type of collisions are demonstrated in the data contained in Figure 65, which shows the occupant fatalities occurring in two vehicle fatal collisions in 1984.

Figure 65. Occupant Fatality Mix in Two-Vehicle Fatal Accidents in 1984



SOURCE: FARS 1984

Two-vehicle collisions are the largest single category of fatality producing motor vehicle/highway related accidents. In 1984, two-vehicle collisions accounted for 37.7 percent (16,668) of all highway related fatalities. Collisions between medium/heavy trucks and other vehicles resulted in 21 percent (3,423) of all the fatalities sustained by occupants of other smaller vehicles involved in two-vehicle collisions. The majority of these victims (71.9 percent, 2,461) were passenger car occupants. In all, these 3,423 fatalities represented 7.7 percent of all the highway related fatalities occurring in 1984.

As could be expected due to the mismatch between the vehicles involved, passenger car and other smaller vehicle occupants are much more likely to be fatally injured than is the truck occupant when the two collide. Table 49 highlights several of the occupant fatality ratios that result when vehicles of mismatched size collide with each other and a fatality occurs. Only collisions between motorcycles and any other type of motor vehicle are more lethal.

Table 49. Occupant Fatalities in Two-Vehicle Fatal Accidents Involving Different Types of Vehicles

Vehicles Involved	Fatalities in First Vehicle Type	Fatalities in Second Vehicle Type	Ratio of Fatalities in First Vehicle Type To Fatalities in Second Vehicle Type
Car/light truck, van	2,596	768	3.4:1
Car/single-unit truck	593	16	37.1:1
Car/combination unit truck	1,868	51	36.6:1
Light truck, van/combination unit truck	528	27	19.6:1
Motorcycle/car	1,372	39	35.2:1
Motorcycle/light truck,van	582	5	116.4:1

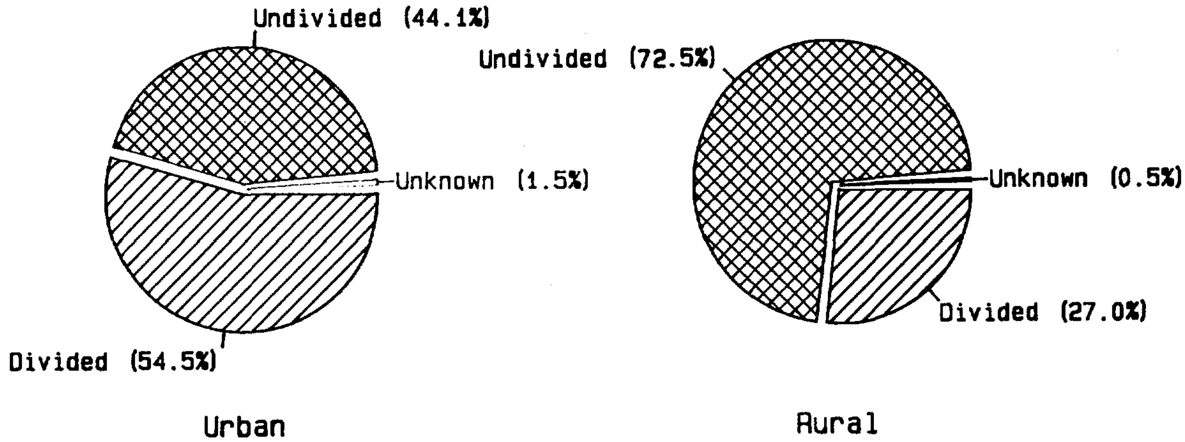
SOURCE: FARS 1984

Fatal collisions between passenger cars and medium and heavy trucks occur most frequently (63.1 percent) on undivided highways. However, when considering rural versus urban operating environments, the picture is somewhat different. In urban environments, fatal car/truck collisions occur almost equally on divided and undivided facilities, whereas in rural environments, most (72.5 percent) occur on undivided roads (Figure 66).

In both operating environments (89.6 percent in rural, and 77.7 percent in urban) the fatal accidents occur on highway facilities that are likely to have comparatively high (45-55 mph) posted speed limits (i.e., Interstates, U.S., and State Routes -- see Figure 67).

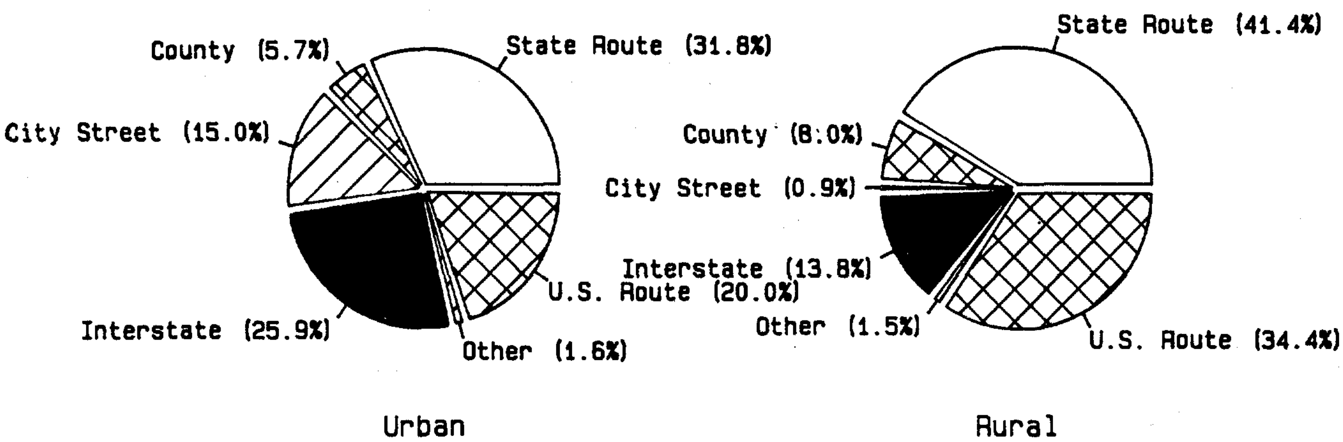
Previous studies have shown that the primary determinant of the level trauma an occupant sustains in a crash is vehicle speed, and more specifically, change of speed upon impact. This is termed Delta V. The general relationship between this index of crash severity and the probability of serious injury (AIS 3 or greater) or fatality is shown in Figure 68.

Figure 66. Fatal Car-Medium/Heavy Truck Collisions by Roadway Separation, and by Environment



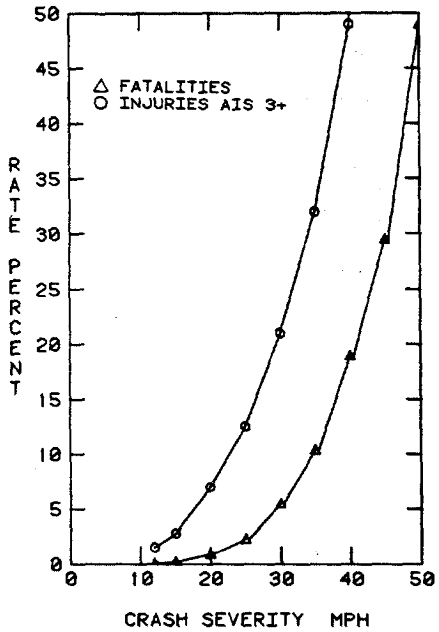
SOURCE: FARS 1984

Figure 67. Fatal Car-Medium/Heavy Truck Collisions by Roadway Type and Environment



SOURCE: FARS 1984

Figure 68. Relationship Between Vehicle Occupant Injuries/ Fatalities and Speed.



SOURCE: Malliaris (1982)

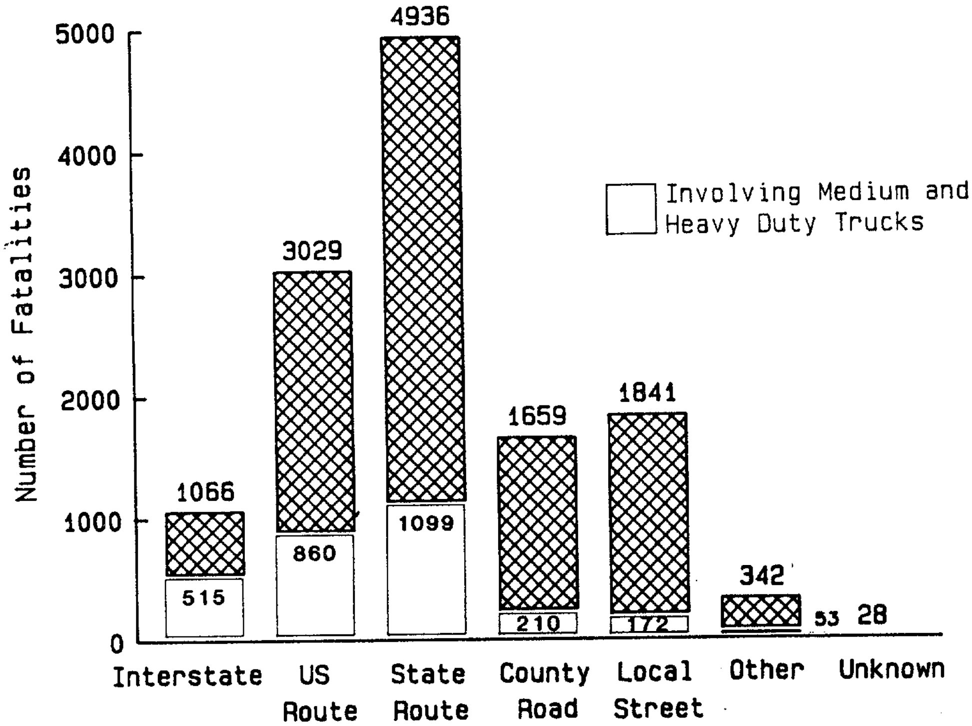
Many medium and heavy trucks, especially combination-unit trucks, travel almost exclusively on high-speed roadways. This factor contributes significantly to the trauma outcomes of many truck accidents. It also partially explains why the majority of passenger car occupant fatalities resulting from car/truck collisions occur on these types of roadways.

In the case of Interstates, 48.3 percent of all passenger car occupant fatalities resulting from multi-vehicle collisions involve collisions with medium/heavy trucks, as can be seen in Figure 69.

Combined, these data tend to indicate that the lethality of car/truck collisions is due in large part to the combination of speed and the opportunity for direct or glancing head-on collisions, combined with the physical mismatch between the two vehicles. In fact, fatal collisions between passenger cars and medium/heavy trucks most often involve front-to-front collisions (28.8 percent), as one can see in Figure 70). Car occupant fatality data for the same type of collisions reflect a similiar pattern (see Table 50).

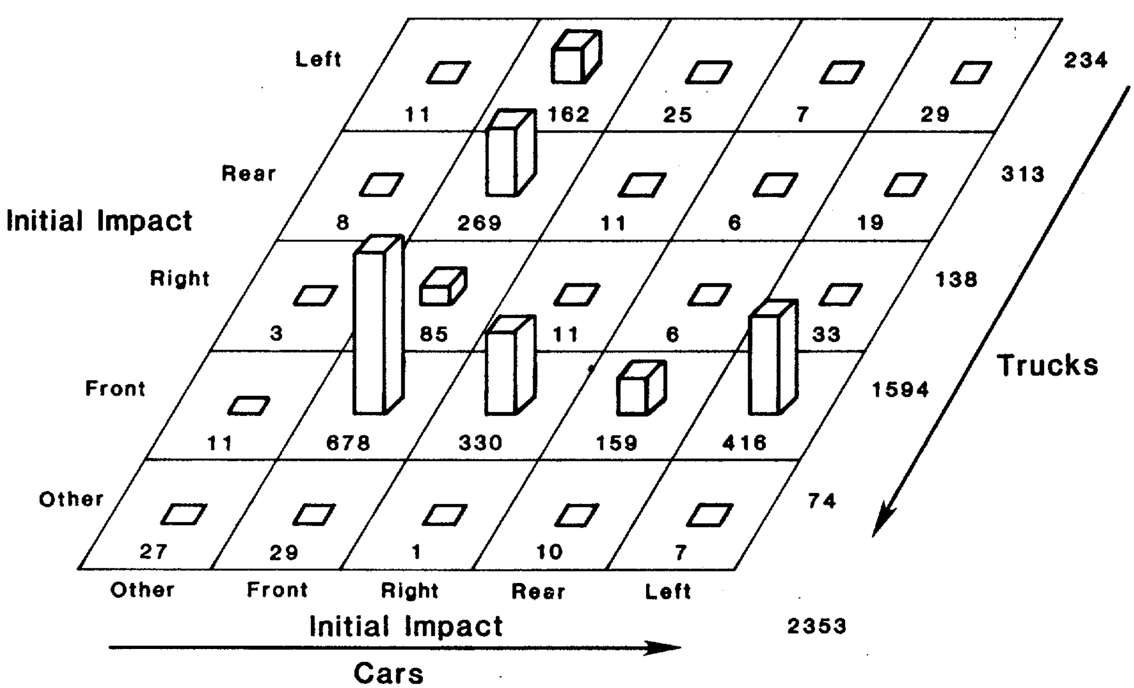
The finding that head-on collisions are so prevalent appears to portray an extremely lethal situation involving full frontal contact of the truck directly into the front, side, or rear of the other vehicle involved. However, this is not the case in all crashes and, therefore, the situation may not be totally unsolvable.

Figure 69. Passenger Car Occupant Fatalities Resulting from Multi-Vehicle Collisions



SOURCE: FARS 1984

Figure 70. Fatal Car-Medium/Heavy Truck Collisions by Point of Impact on Both Vehicles



SOURCE: FARS 1984.

Table 50. Car Occupant Fatalities In Collisions Between Cars and Medium/Heavy Trucks

Part of Car Impacted	Manner of Collision					
	Rear end	Head on	Angle	Sideswipe Same Direction	Sideswipe Opposite Direction	Total
Front	274	791	395	21	49	1,530
Right side	12	113	375	13	6	519
Rear	171	17	31	5	1	225
Left side	15	62	485	38	35	635
Total	472	983	1,286	77	91	2,909

SOURCE: FARS 1984

Table 51 shows in more detail how the fronts of medium/heavy trucks contact each of the four quadrants of a car when the two are involved in a fatal collision. If it is assummed that collisions involving any portion of the front of a truck (ie., truck impacted part = 11, 12, or 1 O'clock) impacting into the direct front, sides, or rear of a car (ie., car impacted part = 12, 3, 6, or 9 o'clock) are not reasonable candidates for improvement, then 83.7 percent (1325/1583) of all collisions would not be addressable. Conversely, however, using this conservative approach, the lethal effects of 16.3 percent of the collisions involving the front of trucks might possibly be ameliprated. A more optimistic estimate (eliminating from consideration only direct truck frontal impacts [ie., truck part = 12 o'clock] into the direct front, sides, or rear of the car [ie., car part = 12, 3, 6, or 9 o'clock] indicates that up to 43.6 percent of these type of collisions might be reasonable candidates for improvement.

THE MECHANICS OF TRUCK AGGRESSIVITY

There are three basic design aspects of heavy trucks which make them "aggressive" when they collide with smaller vehicles, which are, for the most part, cars: the truck's weight, which can be as much as 40 times that of a car; the stiffness of the truck's structure; and the height of this structure above the ground.

The large ratio of the truck's mass to the car's mass and the principle of conservation of momentum dictate that when cars and trucks collide, the velocity change of the car will be much greater than that of the truck. For example, a direct head-on collision between an 80,000 lbs truck and a 2,000 lbs car, each travelling at 20 mph, will result in the truck only being slowed to 19 mph, while the car will be accelerated backwards to a speed of 19 mph (for a total change of velocity of 39 mph). This mass ratio effect is so great that even if the truck weighed significantly less, the effect is almost the same. (If, in the case described above, the truck's weight was half, 40,000 lbs, the car's velocity change would still be 38 mph).

Table 51. Vehicle Orientations: Fatal Collision Accidents Between Medium/Heavy Trucks and Cars in Which the Front of the Truck Is Either the Striking or Struck Portion Affected

Part of Car Impacted	Part of the Truck Front End Impacted (In O'Clock Positions) 11	12	1	Total
Frontals				
11	94	42	23	159
12	64	370	21	455
1	15	30	19	64
Right side				
2	18	47	5	70
3	20	200	10	230
4	3	20	7	30
Rear end				
5	8	9	3	20
6	5	105	12	122
7	2	5	10	17
Left side				
8	8	23	13	44
9	25	218	28	271
10	14	71	16	101
	----	----	----	----
Total	276	1,140	167	1,583

Source: FARS 1984

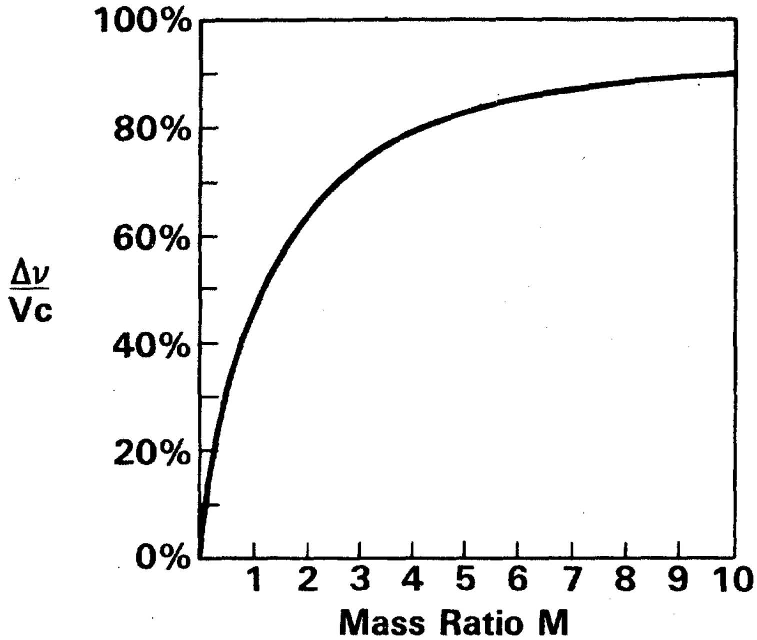
Mackay and Walton (1984), in a discussion of this phenomenon, noted that if there is no elastic rebound between the two vehicles (which is typically the case in car/truck collisions), the velocity change of the car is given by the following equation:

$$V = \frac{M}{1 + M} \times V_{cl}$$

where: M = Mass (truck)/Mass (car)
V = Velocity change of the car
V_{cl} = Relative closing velocity between the two vehicles (i.e., $V_t - V_c$)

Figure 71 illustrates how the velocity change of the car increases with increasing mass ratio. At ratios much above 5:1, the velocity change of the car essentially becomes the closing speed between the vehicles.

Figure 71. Effect of Mass Ratio on Velocity Change



Since trucks are designed to carry heavy payloads, their frames are big and, therefore, extremelly stiff when subjected to frontal collision-induced compression loads. As a result they do not generally deform much in a collision and therefore absorb little of the kinetic energy generated in a crash.

This fact was evident in the truck frontal crash test reported by Rice and Shoemaker (1982). They ran a combination-unit truck loaded to 35,000 lbs GCW into an array of collapsing barrels at 35 mph in order to study truck occupant protection issues. They noted, coincidently, that crash loads were taken out by the truck's two longitudinal frame rails which are the vehicle's two main load bearing members, and which extend to the very front of the truck (see Figure 72). Under these test conditions, the entire vehicle acted as a rigid unyielding column with crash-induced load essentially being transferred equally and almost instantaneously throughout the length of the combination-unit vehicle.

This being the case, when cars and trucks collide, practically all the deformation occurs in the car. This fact is particularly evident in the data shown in Figure 73, where it can be seen that car damage severity in combination-unit truck/car collisions is generally much higher than that of the truck.

Figure 72. Typical Heavy Truck Frame

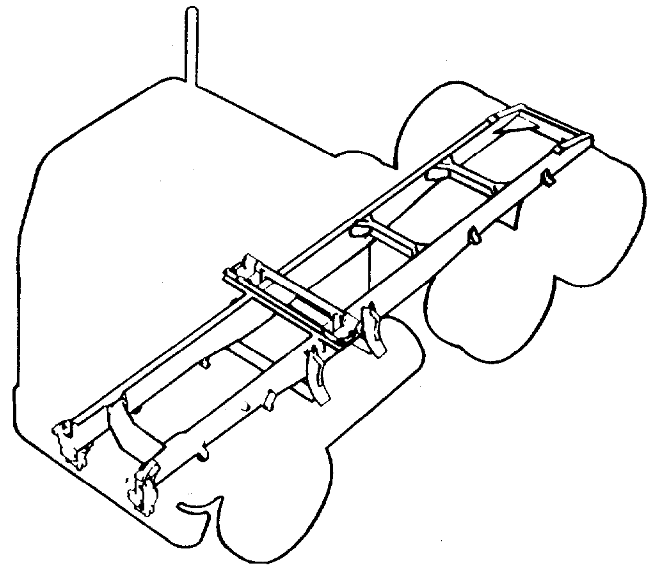
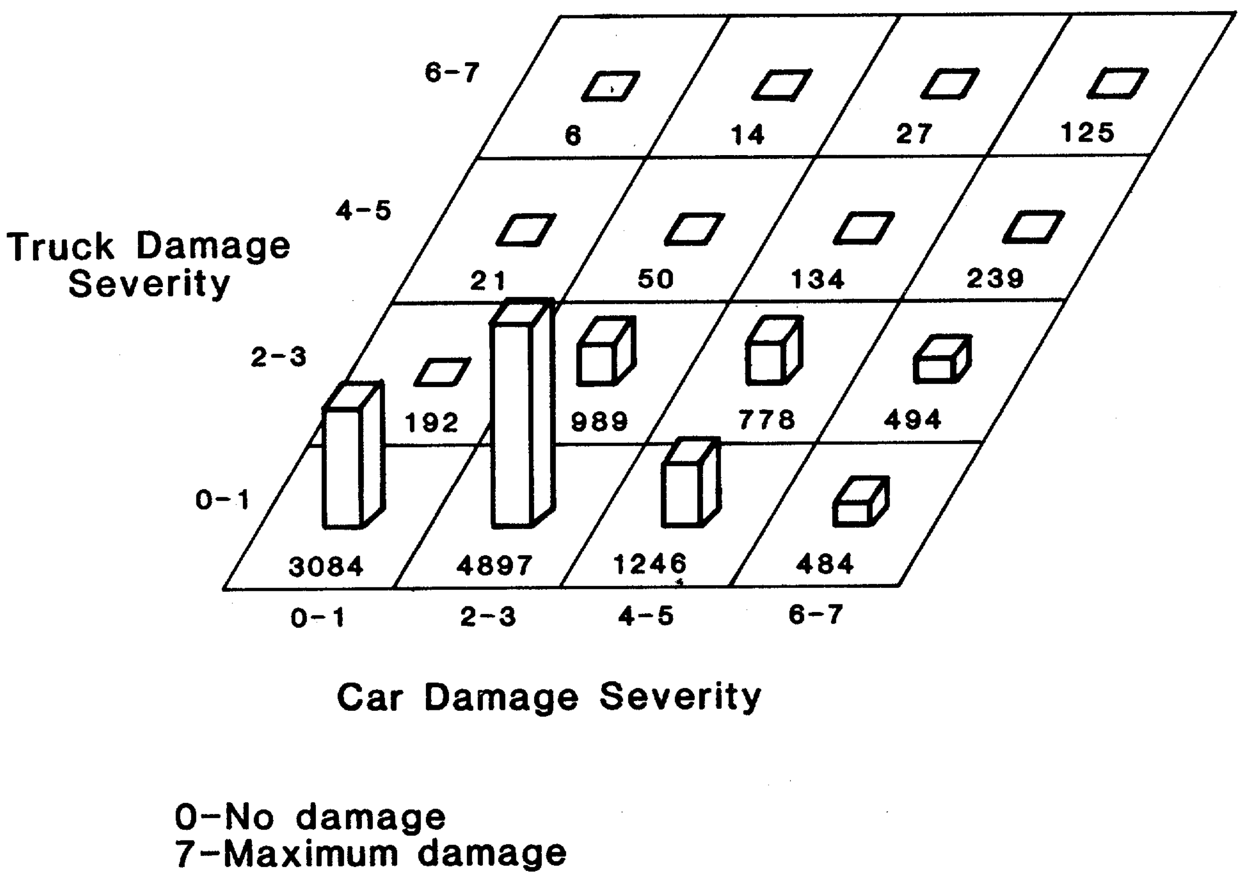
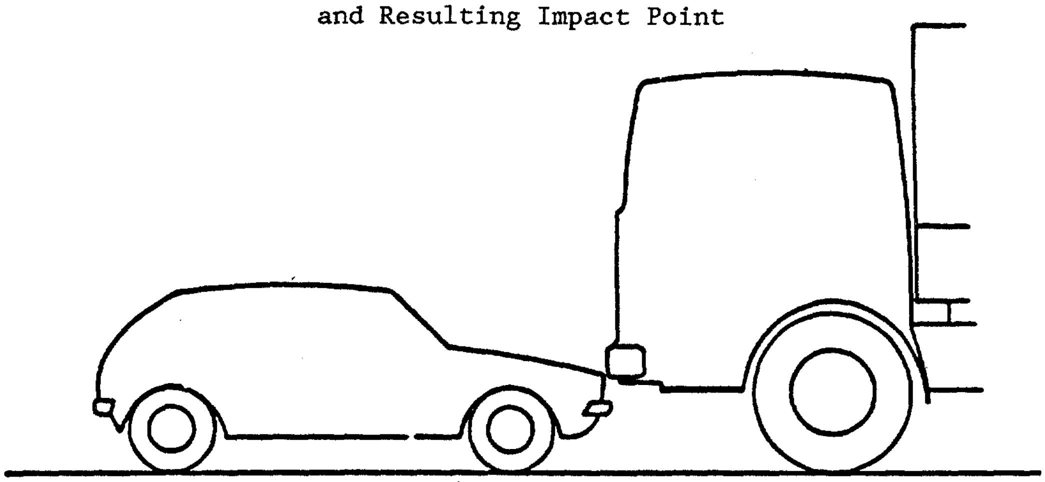


Figure 73. Vehicle Damage Severity Outcomes for Car/Combination-Unit Truck Collisions in Texas (1981-1983)



In many car/truck collisions in which the front or rear of the car is the impacted area, the car's bumper and designed-in structural energy absorption capability are not utilized. Most often this is because the truck's front or rear bumper or body structure is higher than the car's. This is often termed "geometric aggressivity" and is depicted in Figure 74.

Figure 74. Relative Height of Bumpers in Car/Truck Frontal Collisions and Resulting Impact Point



Some truck operators remove the ends of the front bumpers of their trucks, (this is typically referred to as "clipping" the bumpers). Ostensibly, this is done to prevent the bumper -- which is unsupported laterally outboard of the vehicle's frame rails -- from being bent backwards in a collision, pinching the steering axle tire, thus making the vehicle unsteerable. The extent of this practice varies. It appears to be most prevalent in the East and the Midwest as the data in Table 52 indicate. This practice exposes the truck's front wheels and could exacerbate the geometric mismatch problem by making it easier for the truck to roll on top of smaller vehicles it might strike.

Table 52. Prevalence of "Clipped" Front Bumpers Among U.S. Combination-Unit Trucks

Location of Sample	"Clipped" Bumpers	Total Vehicles Sampled
Maryland	577 (16.9%)	3419
Illinois	566 (26.0%)	2174
Texas	35 (4.0%)	873
California	152 (3.8%)	3955

SOURCE: Kirkpatrick (1986), Wakeley (1986), Cunagin (1986), and Smith (1986)

Geometric mismatch can result in underride, if the car strikes the truck and slides underneath, or override if the truck strikes the car climbing on top of it. In either case the car ends up underneath the truck with its passenger compartment severely damaged, greatly increasing the probability of car occupant serious injury or death. The photographs in Figures 75 and 76 indicate override in one case and underride in the other.

Figure 75. Override

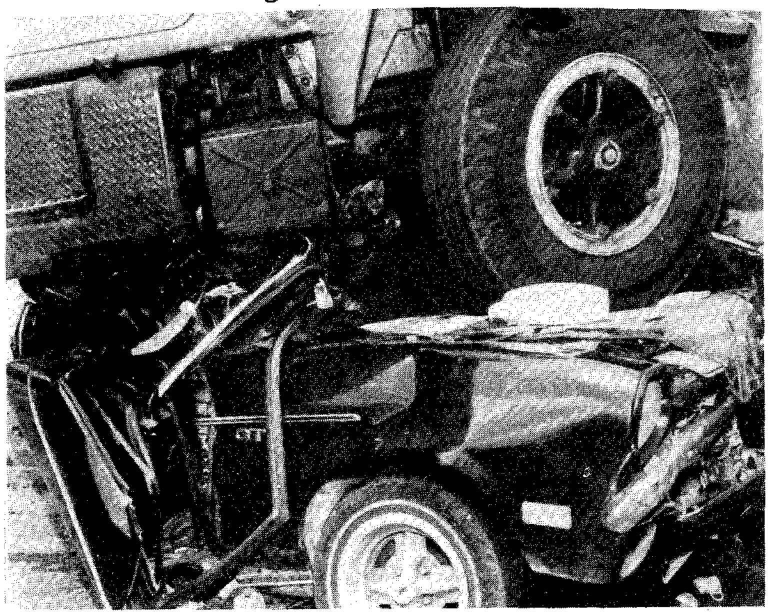
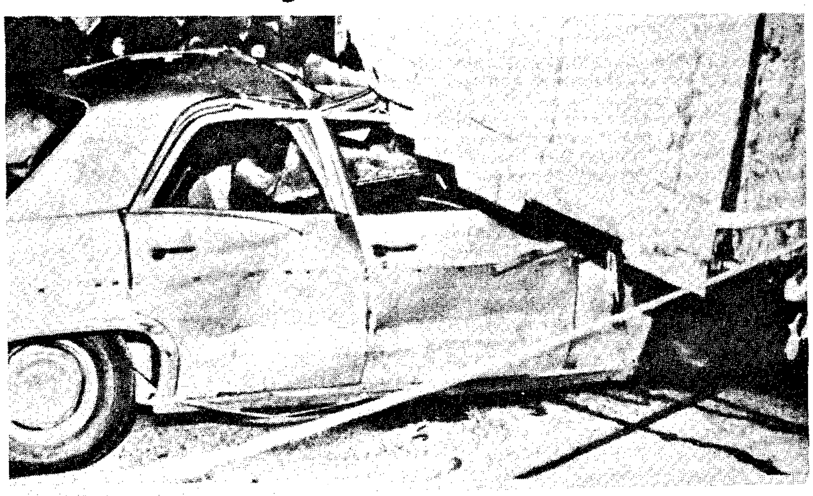


Figure 76. Underride



RELATED PREVIOUS WORK

Front End Protection

Recently, there have been several European research programs directed towards determining whether improvements to the fronts of trucks could be made in this regard.

Danner and Langwieder (1981) conducted a series of car-front-to-truck-front and truck-front-to-car-side crash tests to determine if different types of bumper systems on the front of trucks would improve car occupant trauma outcomes. They tested cars ranging in weight from 1000-1600 kgs and trucks weighing 8.9 tonnes. The orientations of the two vehicles in the tests are shown in Figures 77 and 78.

Figure 77. Impact Position in the Frontal Car/ Truck Crash Test

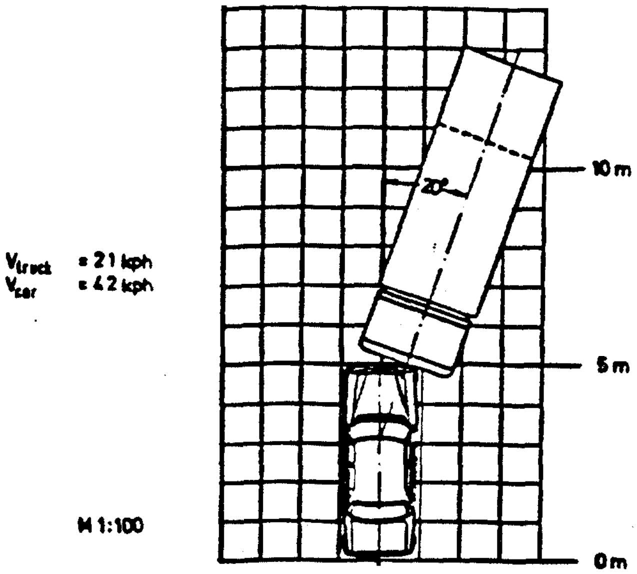
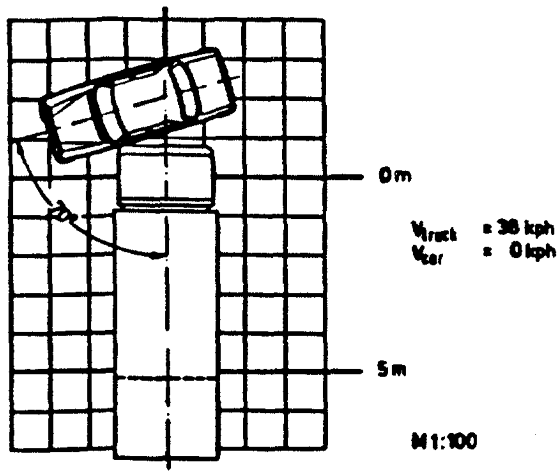


Figure 78. Impact Position in the Lateral Car/ Truck Crash Test



Two sets of tests were run, one with a rigid bumper mounted somewhat lower than the truck's original bumper (this bumper was 420 mm. above the ground) and another set with an energy absorbing bumper mounted at a height of 310 mm.

Both vehicles were moving in the frontal crash tests, the car being pulled by the truck via a cable and pulley system. Relative closing velocity was 63 kph in the frontal tests and 39kph for the side impacts. In both sets of tests, a driver actually drove the truck into the cars with apparently no serious consequences except, " ...slight pressure in the area of the belts for one day after the tests".

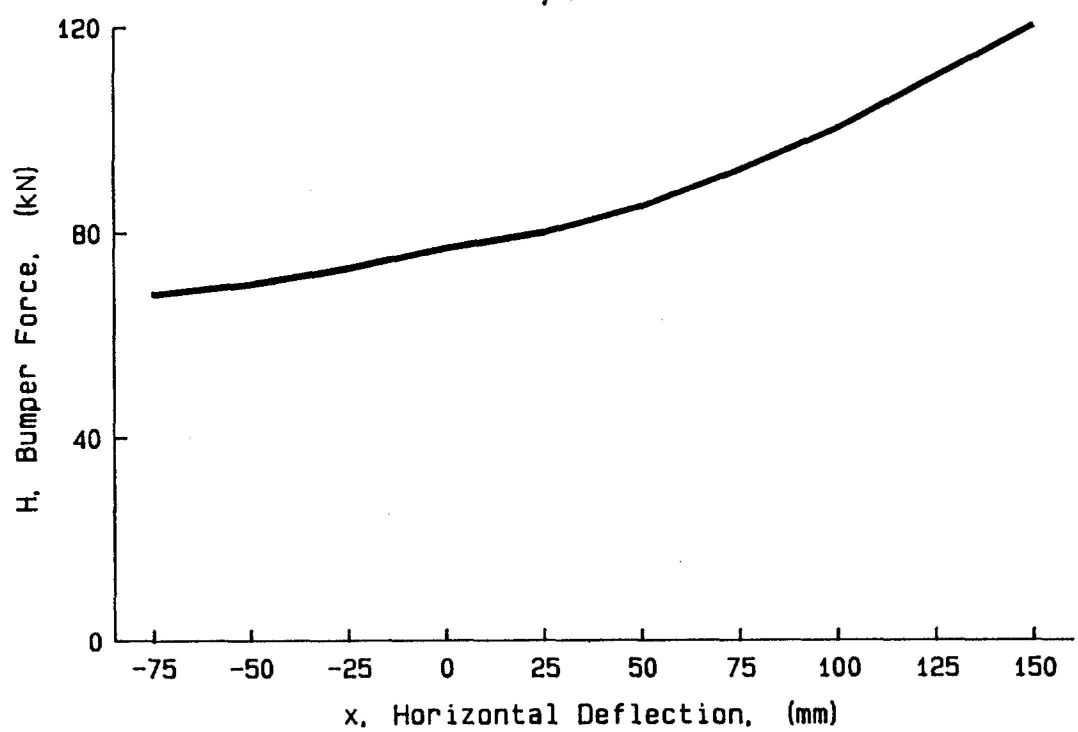
In the frontal tests, truck decelerations were around 10 g's with some higher instantaneous peaks, while car decelerations reached 50 g's with the rigid bumper and 40 g's with the energy absorbing bumper. In the side impacts, the truck decelerations ranged from 5-10 g's.

The authors concluded that geometric aggressivity was reduced for the front-to-front cases by both modifications but the rigid bumper still imparted too much force to the car. The energy absorbing bumper offered improvement potential in the front-to-front case, since it both absorbed energy and disengaged and deflected the car after initial impact. The side impact cases were less successful even with the energy absorbing bumper because of excessive side intrusion into the car's passenger compartment area. This was reduced 20-40 percent, however, in the case of the energy absorbing bumper because the car's side sill was contacted. Overall, they concluded that in some cases improvements were possible in car occupant protection by fitting trucks with frontal energy absorbing systems but that further work was needed to develop appropriate specifications for the system.

Penoyre and Riley (1984) conducted a similar series of car/truck front-to-front crash tests, except these were direct frontals with no off-alignment. Nine cars ranging in weight from 1000-1550 kgs were impacted at speeds ranging from 40-64 kph into the front of a standing 5100 kgs truck wedged against a wall. The work was patterned after similar British work done to enhance truck rear-end underride prevention/energy absorption capability.

Based on their test results, the authors theorized that if a device were fitted to the front of trucks that had force/deflection characteristics as shown in Figure 79 and dimensional specifications essentially equivalent to those specified for rear underride guards (ECE Directive 70/221), substantial improvement in both underride prevention and car occupant injury/fatality prevention would be achieved.

Figure 79. Proposed Force/Deflection Characteristics for Truck Front Ends



SOURCE: Penoyre and Riley (1984)

Mr. Jean Block, at the June 3-5, 1986 Annapolis Symposium, reported on car/truck crash test work he is doing at INRETS in France, to study front end aggressivity of trucks in truck/car collisions. He noted that truck front ends are involved in 50 percent of the French car/truck accidents fatal to a car occupant. Only preliminary test results were reported but he noted that geometric mismatch between the vehicle structures resulted in only two thirds of the car's structure contacting the truck's higher structure. In addition, he has concluded that a combination of traditional biomechanical criteria as well as maximum acceptable deformation criteria will be needed to determine the survivability of car occupants in these types of crashes.

Side Protection

Several countries (Belgium, The Netherlands, Luxembourg, and the United Kingdom) have requirements for side underride guards. They are intended to prevent pedestrians and pedacyclists from falling under the wheels of the trailer, which is a significant problem in those countries, but not in the U.S.. None of the requirements envision guards strong enough to prevent cars from underriding the sides of trailers should they impact them in this area.

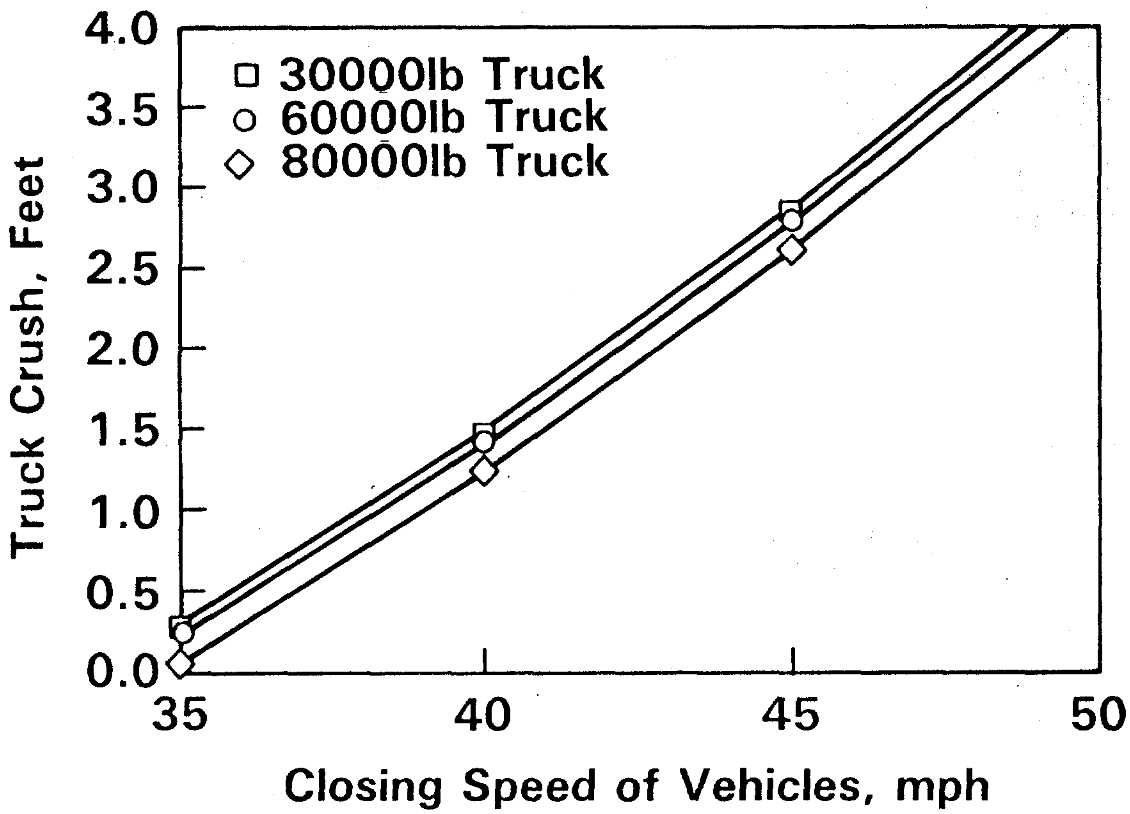
THE DYNAMICS OF TRUCK/CAR COLLISIONS

Expanding on the concept outlined by Penoyre and Riley (1981), it is instructive to analyze the dynamics of a frontal car-truck collision from the perspective of considering various kinds of energy management systems that might conceptually be built onto the front end of medium and heavy trucks. The primary performance goal of such an energy management system would be the reduction of injury trauma inflicted on car occupants who are involved in collisions with trucks. To accomplish this goal, a design would have to: limit the amount of intrusion by the truck into the passenger compartment of the car, and; limit the amount of kinetic energy that the car and its occupants have to withstand to levels that otherwise would be acceptable.

Ideally, in full-frontal or offset-frontal collisions between trucks and cars, the total kinetic energy of both the vehicles would be consumed by the deformation of the structures of both vehicles while simultaneously meeting the two conditions stated above. Due to the large mass differential between the two vehicles, it is not realistic to think that, for very high speed differentials, all the kinetic energy of impact could be managed in this manner. However, if it is assumed that car structures are, by themselves, capable of protecting car occupants in frontal collisions at delta v's of 30-35 mph, incremental improvements might be possible if truck front end structures were designed to absorb some, as yet unspecified, added amount of kinetic energy.

It can be shown analytically, by applying the principles of linear conservation of momentum and energy (ignoring internal friction losses), that for various relative closing speeds between the two vehicles, truck front end crush distances as shown in Figure 80 would be needed to produce a car crash event equivalent to a 35 mph barrier crash of the car alone.

Figure 80. Estimated Truck Front End Crush Distance Needed to Produce a Car Crash Event Equivalent to One at 35 MPH



The plot shown in Figure 80 highlights a number of interesting points. First, since trucks are comparatively much heavier than cars, increases in the truck's weight matter little in this consideration. Nevertheless, the graph does indicate that, for closing velocities of 38-40 mph, a truck front end that could crush 1.0-1.5 feet might result in a car crash event that was equivalent to an otherwise acceptable one at 35 mph, this for a car assummed to weigh 3,000 lbs and truck weights ranging from 30,000 lbs to 80,000 lbs.

At closing velocities higher than this, a combination of absorption and deflection might be possible wherein the truck front end yields and then becomes rigid at an oblique angle, handling the residual kinetic energy of impact through deflection. This concept needs further study, however. Deflection, while preferable to override or other excessive intrusion into the car passenger compartment, does create the potential for subsequent lethal secondary collisions with oncoming or parked vehicles, trees, or pedestrians. Figures 81 and 82 are examples of conceptual truck front end designs which might accomplish these objectives.

Figure 81. Compression-strut Concept for an Energy-Absorbing, Heavy Truck Front End Design

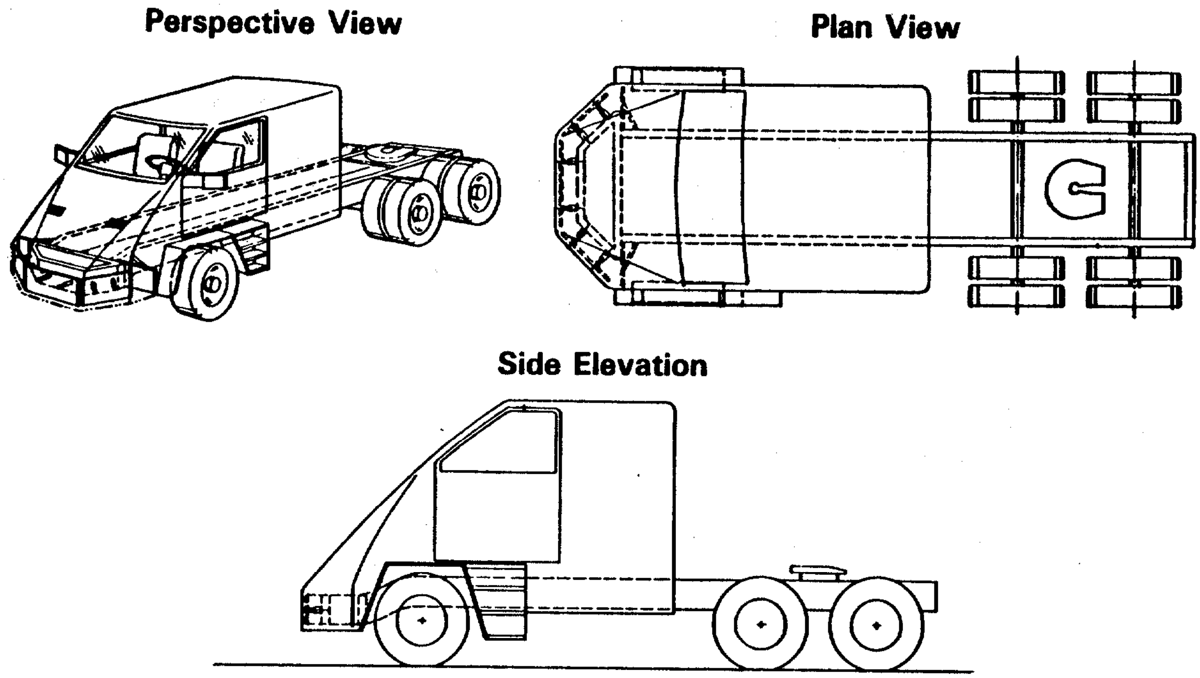
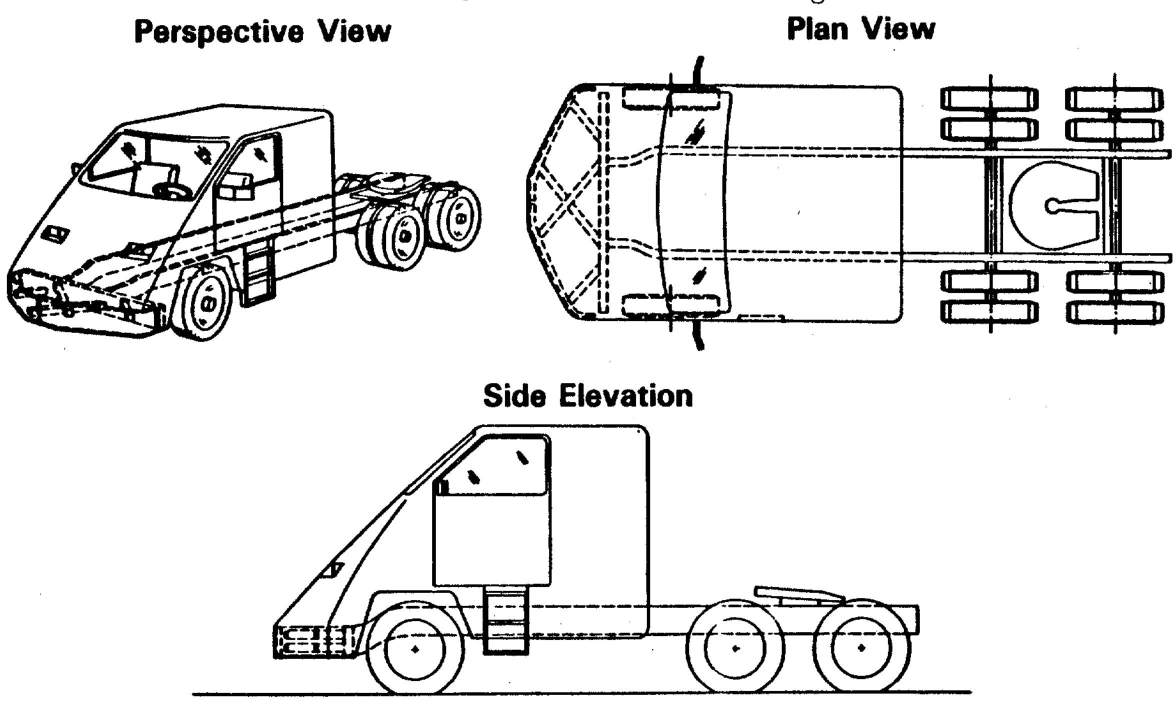


Figure 82. Bending-Beam Concept for an Energy-Absorbing, Heavy Truck Front-End Design



It is recognized that designs such as these would add weight and length to the tractor and may restrict some functional use applications (for example off-road logging or construction). Ultimately the incorporation of such design concepts, should they be deemed to be feasible, may only be both practical and needed in selected applications and might best be considered only as part of a comprehensive package if vehicle weight and length restrictions are changed.

RECOMMENDED RESEARCH PLAN FOR REDUCING HEAVY TRUCK AGGRESSIVITY

Introduction

The extent to which the effects of collisions between medium/heavy trucks and other smaller vehicles can be ameliorated is not clear. However, given the appreciable number of occupants of other smaller vehicles (3423) who are killed in collisions of this type, it appears worthwhile to study the possibility that even small incremental improvements can be achieved. The accident cited at the beginning of this section is an example of a crash which might have had a different outcome if the truck had a different front end design.

It seems likely that the survival probability of car drivers involved in car/truck collisions would increase if geometric mismatches could be eliminated and if some energy absorption capability could be built into the vehicle. In the case of collisions involving the front of trucks, some additional vehicle redirection capability might also be needed to accommodate residual kinetic energy not dissipated through vehicle deformation.

Based on the fact that 67.7 percent of the fatal car/combination-unit truck collisions involve the fronts of trucks, it appears worthwhile to assess whether truck frontal area impact attenuation/aggressivity reduction is possible. In the context of truck occupant protection, the truck frontal area needs addressing as well. As a result, efforts to design truck frontal structures to prevent override of cars and to absorb some impact kinetic energy may also help reduce the likelihood of trucks climbing roadside guardrails/barriers and overturning as well as ameliorating frontal impact effects on truck occupants. Thus, it appears that improvements might be possible for both truck occupants and occupants of other smaller vehicles struck by trucks by working on truck frontal structures.

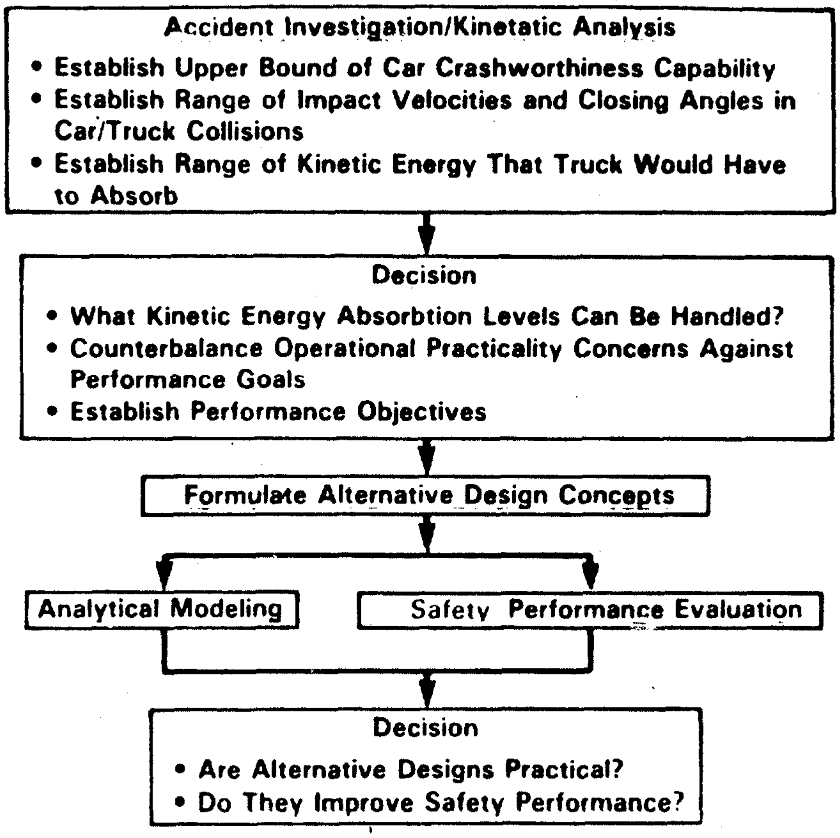
The next highest proportion of fatal car/combination-unit truck collisions (15.8 percent of the total) are those in which the sides of the truck are the area of contact. Conceptually, there appears to be little that could be done to change the designs of trucks in order to enhance car occupant protection in this regard. The best hope of reducing the number of these fatalities may lie with crash avoidance efforts designed to improve other aspects of the truck, such as conspicuity, lighting, and indirect field of view.

Based on this reasoning, truck front ends seem the most likely candidate for further research.

Frontal Impact Attenuation/Override Prevention Research Program

Efforts to improve truck front end designs to make them less aggressive would benefit from being done in parallel with the program to improve crash truck occupant protection since, ultimately, many design and performance targets would have to be compatible, if not identical. Nevertheless, the program could be undertaken independently. The program includes several projects as shown in Figure 83:

Figure 83. Proposed Research Program Plan
Frontal Impact Attention/Aggressivity Reduction



Accident Review/Kinematic Analysis

This project involves a review of current car crashworthiness capabilities to determine an upper bound of energy absorption capability for cars. These data would, in turn, be input for a theoretical analysis of truck/car collisions with assumed ranges of closing velocities and orientations of impact to determine how much remaining kinetic energy would have to be absorbed by the truck to preclude excessive force from being transmitted to the car. This analysis would lead to estimates of how much crushing distance (assuming force/deflection and deflection/time properties of various available materials or energy absorption design techniques) would theoretically have to be built into the front of the truck to accommodate the range of car/truck collisions that occur. Answers from this analysis would be "filtered" against real-world operational practicality limitations/considerations to arrive at design and performance targets for truck front ends that represent a reasonable balance between ultimate performance goals and designs which can be practically achieved. Any residual kinetic energy not dissipated by these designs would have to be handled through redirection and disengagement of the two vehicles.

Development of Analytical Modeling Techniques

This project involves modifying existing passenger car lumped mass and finite element models that predict vehicle structural response to crash-induced crushing loads to make them suitable for use with medium/heavy trucks. This project would run in parallel with the other projects in the program. Ultimately, the output/products of this project would be used as performance verification and design development tools.

Formulate Alternative Design Concepts

This project would involve parallel track efforts at several organizations to develop conceptual designs of frontal systems that meet the design and performance targets established in the first project. Once developed, these concepts would be submitted for a critical peer review which would evaluate each against the following criteria:

- likelihood of attaining performance/design targets
- practicality/feasibility
- manufacturability
- cost
- appropriateness for as wide a range of truck types and vocations as possible.

Based on the results of this review, a decision could be made about the appropriateness and direction of further research work.

SECTION 6. TRUCK DRIVER COMPLIANCE WITH TRAFFIC LAWS

INTRODUCTION

Primarily because of the size and weight of trucks, there are limitations on the abilities of drivers to operate them safely, especially in emergency situations. Regardless of any improvements made to these vehicle characteristics or, for that matter, to the roadways and other features of the operating environment, the manner in which a vehicle is driven will always play a paramount role in the safe operation of that vehicle.

Knowledgeable and experienced drivers of large trucks who want to operate safely take into account vehicle limitations and environmental conditions. For example, they operate at speeds safe for conditions; they give adequate advance signals of lane changes and turning maneuvers and execute the maneuvers smoothly and properly; they maintain adequate following distances to allow for slowing and stopping in a manner so as to avoid fishtailing, jackknifing, tailgating, and other actions that would threaten their own safety as well as that of other road users; in general, they follow the "rules of the road" with an extra margin of safety and courtesy.

One of the roles of police traffic enforcement agencies is to assure that commercial vehicles and drivers are in compliance with State traffic laws and regulations. For a number of reasons, enforcement activities against unsafe drivers of heavy trucks are difficult. In some cases, traffic law enforcement directed towards heavy trucks is limited due to resource constraints. This is especially true where police agencies are responsible for other activities (such as vehicle inspection or size and weight enforcement), or have other special traffic safety activities to perform, such as campaigns against drinking and driving. Enforcement activities have been difficult even where they are supported, due to the limited number of traffic officers available in comparison to the volume of traffic and to technological advancements that make "catching" violators of certain traffic laws difficult -- specifically, the almost universal use of citizens band (CB) radios and radar detectors by truck drivers.

This section of the study addresses truck driving behavior as it relates to heavy truck crashes, traffic violations, and the role of police enforcement in mitigating unsafe truck driving behavior. The objective is to: gain a clearer picture of those enforcement activities that may offer the best chance of success in addressing the issue; provide a basis for identifying ways in which current programs may be improved; and identify the needed research activities that would improve enforcement procedures.

METHODOLOGY

Most of this section was developed from available information. Two new information gathering activities were performed, however. The first was a literature review update. Already completed related searches on broader truck topics were examined and relevant information was extracted for this study. The purpose of the literature review was to define the problem, i.e., to identify the relationships between large truck crashes and unsafe driving behaviors. Specifically, data related to the following types of truck driving behaviors were sought:

- Speed.
- Vehicle following distances.
- Lane changing maneuvers (including signaling).
- Entering and exiting at interchanges.
- Vehicle registration.
- Exposure (mileage data).
- Other violations.

The second new activity was to identify existing police enforcement strategies that relate specifically to truck driving behavior and, based on a sampling of several States, to document the strategies used. The purpose of the activity was to determine what strategies were working or not working, and what practical actions could be taken to improve enforcement programs relative to truck drivers. Information was obtained from: police contacts provided by the Police Traffic Services Division, Traffic Safety Programs, NHTSA; a nationwide survey of State law enforcement agencies conducted by the Florida Highway Patrol; a survey of a limited number of truck drivers in the Charlotte, NC area conducted by the University of North Carolina, Charlotte; interviews with several trucking companies; and submissions to the NHTSA Docket concerning this study.

The enforcement issues addressed include:

- Police agency understanding of the extent of unsafe driving behavior by truck drivers;
- Enforcement strategies used and, where available, information relative to the effectiveness of those strategies;
- Methods used by truck drivers to circumvent enforcement activities; and,
- Police-perceived impediments to more effective enforcement activities (e.g., legal, technical, fiscal, institutional)

FINDINGS

Law Enforcement Perspective

Information was obtained from various State police agencies to gain a better understanding of those agencies' knowledge concerning unsafe driving behaviors of truck drivers; to find out what enforcement strategies are being used and how successful or unsuccessful they are; and to identify what police perceive are some of the impediments to more effective enforcement activities targeted at unsafe truck driving.

Understanding the Problem

In the Spring 1986, the Florida Highway Patrol completed a nationwide survey of State law enforcement agencies to determine the types of techniques used in truck enforcement programs. Florida did not survey itself, nor was Hawaii, which does not have a State Police or Highway Patrol agency, surveyed. All the other States were surveyed. Forty of the 48 States (83 percent) felt they had a problem with trucking as it relates to highway safety. Thirty-two States (67 percent) felt that the problem had escalated in the past one to two years.

Even though trucks are considered to be a traffic safety problem by most of the State police agencies, data to support this viewpoint are not available. Frequently, truck related data are maintained by different State agencies and often are not available in the detail that would be useful. For example, citation data often are not characterized by type of vehicle. Similarly, speed data are not available for commercial vehicles in many jurisdictions. The most frequent type of data collected is crash/accident information.

In California, 50.9 percent or 17,900 of the 35,200 crashes involving a truck in 1985 were determined by the investigating officers to be caused by the truck or its driver. Those crashes represented 6.9 percent of the total 513,000 crashes occurring during 1985.

The proportion of truck-involved and truck-at-fault traffic crashes to total crashes in California reflect increasing, parallel trends over the eleven quarters from January 1984 through September 1985. The truck-at-fault crash trend, however, is increasing at a slightly faster rate than the truck-involved crash trend. Over the past 11 years, truck-involved and truck-at-fault crashes have shifted in the same direction from year to year as total motor vehicle crashes. From 1975 to 1978 each increased, from 1979 to 1982 each decreased, and from 1983 through September 1985 each increased again. Throughout the 11 years, truck-at-fault crashes have ranged between 2.7 and 3.5 percent of total motor vehicle crashes, truck-involved between 5.9 and 6.9 percent, and truck-at-fault between 43.4 and 53.0 percent of truck-involved crashes. Table 54 includes the yearly accident figures, the percentages, and percentage changes for each of the years from 1975 through 1985.

Table 54. California Trends in Total Motor Vehicle, Truck- Involved, and Truck-at-Fault Accidents, 1975 to 1985

YEAR	MOTOR VEHICLE ACCIDENTS						TRUCK INVOLVED % TOTAL MTR. VEH. ACCIDENTS	TRUCK AT FAULT AS % TOTAL MTR. VEH. ACCIDENTS	TRUCK AT FAULT AS % TRUCK-INVOLVED ACCIDENTS
	TOTAL ACCIDENTS		TRUCK-INVOLVED ACCIDENTS						
			TOTAL		TRUCK AT FAULT				
		(a)		(a)		(a)			
1975	478,455		28,021		14,496		5.9	3.0	51.7
1976	493,103	+3.1	30,027	+ 7.2	15,838	+ 9.3	6.1	3.2	52.7
1977	515,828	+4.6	31,985	+ 6.5	16,939	+ 7.0	6.2	3.3	53.0
1978	551,328	+6.9	36,481	+14.1	18,162	+ 7.2	6.6	3.3	49.8
1979	534,096	-3.1	36,383	- 0.3	16,939	- 6.7	6.8	3.2	46.6
1980	486,444	-8.9	30,724	-15.6	13,326	-21.3	6.3	2.7	43.4
1981	472,150	-2.9	28,892	- 6.0	12,771	- 4.2	6.1	2.7	44.2
1982	448,130	-5.1	26,651	- 7.8	12,149	- 4.9	5.9	2.7	45.6
1983	469,492	+4.8	29,130	+ 9.3	14,066	+15.8	6.2	3.0	48.3
1984	491,449	+4.7	33,676	+15.6	16,781	+19.3	6.8	3.4	49.8
1985(E)	513,000	+4.4	35,200	+ 4.5	17,900	+ 6.7	6.9	3.5	50.9

(a): Year-to-year percent changes.
(E): Annual estimates forecast from January to September 1985 data.

Source: California Highway Patrol.

Although yearly changes in the California truck-involved and truck-at-fault crashes have shifted in the same direction as total motor vehicle crashes, the magnitudes of those changes are not parallel. For example, the most dramatic deviations occurred in 1980 and 1984. In 1980, total traffic crashes dropped 8.9 percent but truck-involved crashes dropped 21.3 percent. In 1984, however, total crashes rose 4.7 percent while truck-involved crashes went up by 15.6 percent and truck-at-fault crashes jumped 19.3 percent. Although the reasons for these differences are not entirely clear, it has been hypothesized that truck activity is related to cycles in the economy and that truck crashes in turn are related to truck activity.

California accident data indicate that, although trucks are involved in a higher percentage of crashes than one would expect based on their exposure as measured by vehicle miles of travel, they are at-fault in fewer crashes than would be expected. However, there is also some indication that truck-at-fault as well as truck-involved crashes are gradually increasing while exposure remains relatively constant. (Compare the VMT figures in Table 55 with the same year figures in Table 54.)

Table 55. California Trends in Total and Truck Vehicle Miles of Travel (VMT), 1981-1984

YEAR	TOTAL VMT (a)		TRUCK VMT		TRUCK VMT AS % OF TOTAL VMT
	(000,000,000)	PERCENT CHANGE (c)	(000,000,000)	PERCENT CHANGE (c)	
1981	160.80	--	6.01	--	3.7
1982	170.00	+5.7	6.17	+ 2.7	3.6
1983	182.65	+7.4	6.49	+ 5.2	3.6
1984	195.99	+7.3	7.23	+11.4	3.7

(a) Source: Caltrans.
(b) Source: Based on diesel fuel purchases reported by truckers to the Board of Equalization.
(c) Year-to-year changes.

On the East Coast, Maryland and Virginia, in December 1984, banned heavy trucks from the left-most lane of 31 miles of the Capital Beltway (I-95 and I-495) around Washington, D.C. in response to rising numbers of truck crashes on that highway Despite the ban, the American Automobile Association (AAA) reports that Beltway crashes involving combination-unit trucks have increased at a rate three times that of other vehicle crashes since the middle of 1984. Combination-unit trucks account for only 3.2 percent of the traffic on the Beltway but for 19 percent of traffic crashes. Motorists were charged by police in only 37 percent of the truck-involved crashes, truckers almost twice as often. While crashes not involving trucks increased by 13 percent, truck-involved crashes increased 43 percent. Trucks running into the rear of other vehicles, truck jackknifes, and loss of control all doubled during the 18 month period.

Ohio had a declining trend in the number of truck crashes between 1978 and 1982. Since 1983, truck crashes in Ohio have increased to levels where in some areas of the State the number of crashes is higher than it has ever been. There were 11,144 truck crashes in 1982 and 16,428 in 1985, a 47 percent increase compared to an 18 percent increase for all crashes. Truck crashes represented 4.4 percent of all crashes in 1984 and 1985 but trucks were involved in 20 percent of those crashes which resulted in injuries or deaths.

Unsafe Truck-Driving Behaviors

States do not collect data regarding traffic law violations by truck drivers as a special class of drivers. Nevertheless, the behaviors, i.e., violations, thought to be unsafe are generally agreed upon among enforcement personnel. Such violations include speeding, following too close, unsafe lane change (either abrupt, erratic, no signal, or a combination of these), improper turn, and driving while intoxicated or driving under the influence (DWI/DUI). Some of these categories may overlap or be termed differently among states. For example, reckless driving in one jurisdiction might be categorized as an unsafe lane change or improper turn in another jurisdiction.

Frequently, violation data related to truck drivers are compiled only when crashes occur, rather than being tabulated as a proportion of all violations. In the AAA Beltway study cited earlier, truck drivers involved in crashes were cited most often (63 percent) for improper lane changes. In comparison, crash-involved car drivers were cited for improper lane changes in 54 percent of their cases. Truck drivers, however, were charged for speeding less often than other crash-involved drivers, 23 percent versus 27 percent.

The State of Ohio analyzed 1982-1985 crashes where truck drivers were at fault. The five most frequent driver errors were improper lane change (7.1 percent), following too close (7.1 percent), failure to control (3.5 percent) improper backing (3.5 percent), and excessive speed (3.0 percent). In crashes where a truck driver was injured or killed, the leading causes of errors were failure to control (20.3 percent), excessive speed (19.2 percent), following too close (11.1 percent), and driving off road for unknown reason (8.9 percent). Comparison data for other drivers were not given.

During a 21 month period from January 1983 through September 1984, driver errors accounted for 89.8 percent of the truck-at-fault crashes in California. The top four categories of "Primary Collision Factors" (the investigating officer's opinion of the immediate cause of the crash) were unsafe speed, accounting for 6,105 (23.3 percent) of the total 26,151 truck-at-fault crashes; unsafe lane changes, which made up 4,177 (16 percent); improper turns, 4,086 (15.6 percent); and starting or backing violations, 2,800 (10.7 percent) of the crashes. The figures for an overlapping 21 month period, from January 1984 through September 1985, show a slight (2.6 percent) increase in these top four categories but driver errors accounted for only a 0.5 percent increase in the overall share of the Primary Collision Factors. The California Highway Patrol notes that the "unsafe speed" category includes, in addition to exceeding the maximum speed limit, "driving at an unsafe speed for conditions, such as on a transition road between freeways in urban areas, inclement weather, and wet or icy pavement."

California maintains records on total citations issued to commercial vehicle drivers; however, these citations also include those for equipment deficienicies and size and weight violations. While important in truck safety considerations, these are not typically considered traffic law violations in the same context as are "moving" violations, such as speeding or following too close. Equipment deficienicies and/or size and weight violations comprised 61.2 percent of the total 351,695 citations issued in 1983. Three fourths of the citations were issued by commercial officers assigned to conduct mechanical inspections and enforcement of laws relative to vehicle weight, load size, registration, and driver hours, at both permanent and portable inspection sites around the State. The other 25 percent were issued by road patrol officers whose primary responsibilities are to enforce laws relating to rules-of-the-road. Road patrol officers' citations to commercial vehicles concentrate on speed violations and other moving hazards. Of the 87,568 citations issued to commercial vehicles by beat officers in 1983, 43.5 percent (38,050) were for moving violations. A breakdown of all California commercial vehicle citations for 1983 is given in Table 56.

Table 56. California Commercial Vehicle Citations, 1983

TYPE OF VIOLATION	NUMBER (PERCENT) OF CITATIONS		
	TOTAL	ISSUED BY COMMERCIAL OFFICERS	ISSUED BY ROAD PATROL OFFICERS
Other Equipment	74,147(21%)	66,963 (19%)	7,184 (2%)
Weight	73,143(21%)	69,262 (20%)	3,881 (1%)
Brakes	67,832(19%)	66,770 (19%)	1,062 (.3%)
Maximum Speed	34,767(10%)	2,499 (1%)	32,268 (9%)
Registration	34,707(10%)	26,785 (8%)	7,922 (2%)
All Other	67,099(19%)	31,848 (9%)	35,251*(10%)
Total Citations	351,695(100%)	264,127 (75%)	87,568 (25%)

* 5,782 of these are for "Other Moving Hazards".

Source: California Highway Patrol.

The State of Washington Utilities and Transportation Commission compiles rather detailed data about citations issued as a result of crashes. In 1984, truck drivers (or their trucks) were cited in 40 percent (2,022) of the 5,051 truck-involved crashes. Drivers of other vehicles involved in truck crashes were cited in only 23 percent (1,185) of the crashes. Table 57 gives a breakdown of citations associated with crashes for all vehicles and for truck crashes by truck driver and other vehicle drivers. In all cases, trucks or truck drivers are cited no more than the average for all vehicles except for deficient equipment citations. While four percent (4,989) of all crashes resulted in citations related to equipment deficiencies, seven percent (343) of trucks involved in crashes were cited for equipment deficiencies and only two percent (64) of other vehicles involved in crashes with trucks were cited for equipment deficiencies.

Commercial vehicle violations reported by the Illinois State Police are also related to motor carrier safety inspections. In 1984, 34.8 percent (10,282 vehicles) of the commercial vehicles inspected were placed out of service; 9,636 arrests (citations) were made and 134,204 warnings issued. The comparable 1985 figures were 31.8 percent (14,730 vehicles) placed out of service, 11,821 arrests, and 156,175 written warnings.

Large numbers of the out-of-service placements were for drivers exceeding the allowable hours of service. The major violations were for unsafe tires, broken springs, and other suspension parts.

Table 57. Contributing Circumstances in 1984, State of Washington Crashes

Causal Factor	All Accidents Number (%)	Truck or Truck Driver in Truck Accidents Number (%)	Other Vehicle or Driver in Truck Accidents Number (%)
DRIVER ERRORS			
Inattention	24,534 (22%)	1,128 (22%)	659 (17%)
Fail to Yield	22,019 (20%)	513 (10%)	445 (11%)
Exceeding Reasonable Speed	18,723 (17%)	670 (13%)	348 (9%)
Alcohol	9,177 (8%)	56 (1%)	141 (4%)
Disregard Stop Sign/Signal	7,326 (7%)	58 (1%)	100 (3%)
Following too Closely	7,409 (7%)	277 (5%)	111 (3%)
Exceeding Stated Speed	4,400 (4%)	55 (1%)	56 (1%)
Over Center Line	2,445 (2%)	120 (2%)	106 (3%)
Improper Passing	1,900 (2%)	71 (1%)	126 (3%)
Improper Turn	N.A.*	271 (5%)	91 (2%)
Apparently Asleep	N.A.	62 (1%)	20 (.5%)
Drugs	N.A.	1 (0%)	5 (.1%)
Failed to Signal	N.A.	22 (.4%)	22 (.6%)
Disregard Warning Sign/Signal	N.A.	25 (.5%)	10 (.3%)
Improper Parking Location	N.A.	46 (.9%)	21 (.5%)
Improper Signal	N.A.	10 (.2%)	7 (.2%)
No Lights/Failed to Dim	N.A.	8 (.2%)	5 (.1%)
DEFICIENT EQUIPMENT	4,989 (4%)	343 (7%)	64 (2%)
OTHER VIOLATIONS	N.A.	606 (12%)	240 (6%)
NO VIOLATION	N.A.	1,674 (33%)	1,627 (42%)
TOTAL ACCIDENTS	111,655 (100%)	5,051 (100%)	3,901 (100%)

Source: Washington Utilities and Transportation Commission
* N.A.= Not Available

Note: In some accidents there were no contributing circumstances noted, while in others there were several noted.

For the 12-month period between October 1, 1984, and September 30, 1985, the Illinois State Police issued a total of 183,203 citations and 108,268 warnings for vehicles violating the 55 mph speed limit on the 14,214 miles of State roads. Generally, citations are given to those going 65 mph or more, and citations or warnings are given for those violations of 56 to 64 mph. When weighted by vehicle miles of travel and adjusted for speedometer variability and statistical error, 36.7 percent of all vehicles in the State exceed the 55 mph speed limit. Unweighted and unadjusted, the percentage of cars exceeding the speed limit is only slightly greater than the percentage of trucks, 57.6 percent vs. 56.7 percent, respectively. The average and median speeds are about the same (56 mph) for both trucks and cars, and the 85th percentile speeds are also the same (see Table 58 for a comparison between truck and car speed data).

Table 58. State of Illinois Speed Data Summary, October 1, 1984 Through September 30, 1985

	Cars (vehicles ≤ 24 ft.)	Trucks (vehicles > 24 ft.)	Total Vehicles
Average Speed	56.0 MPH	56.4 MPH	56.0 MPH
Median Speed	56.3 MPH	56.1 MPH	56.3 MPH
85th %-ile	63.5 MPH	63.2 MPH	63.5 MPH
	Percentage of vehicles exceeding		
50 MPH	80.5 %	81.4 %	80.6 %
55 MPH	57.6 %	56.7 %	57.4 %
60 MPH	27.1 %	25.4 %	26.9 %
65 MPH	9.6 %	9.1 %	9.5 %
70 MPH	2.7 %	3.2 %	2.8 %

Source: Illinois Department of Transportation

Virginia State Police issued 24.3 percent of its 1985 violations to commercial vehicles. Again the totals include equipment/inspection and size and weight violations. If these categories are excluded, commercial vehicle citations account for only 12.8 percent of the total violations. A breakdown of the violations is given in Table 59. The largest category of violation by far is speeding, which accounted for 216,735 violations (44 percent of the total violations); commercial vehicles received only 8.5 percent of the speeding violations.

Table 59. Virginia Commercial and Total Vehicle Citations, 1985

TYPE OF VIOLATION	COMMERCIAL VEHICLE CITATIONS	NON-COMMERCIAL VEHICLE CITATIONS	TOTAL CITATIONS
Speeding	18,504 (4%)	198,231 (40%)	216,735 (44%)
Size and Weight	60,796 (12%)	2,375 (.5%)	63,171 (13%)
Equipment/Inspect	9,302 (2%)	32,750 (7%)	42,052 (9%)
Reckless	1,332 (.3%)	33,330 (7%)	34,662 (7%)
DUI	148 (.03%)	10,008 (2%)	10,156 (2%)
Traffic Other	29,301 (6%)	95,424 (19%)	124,725 (25%)
Total	119,383 (24%)	372,118 (76%)	491,501 (100%)

Source: Virginia State Police.

Considering all this information, the driving behavior of truck drivers may be no better or worse than the behavior of drivers of other types of vehicles. It does appear, however, that a larger portion of truck-related enforcement effort is directed towards equipment/size and weight laws than is directed towards traffic safety laws related to driving behavior. For example, where state data was available for truck crashes, driver error was noted in the vast majority of cases as being the primary cause of the crash, yet, in those same jurisdictions, traffic safety law violations were only a small part of the total truck violations issued by the police. Driver error is the primary cause noted in crashes of other types of vehicles as well, but in these cases, traffic law violations issued to drivers of these other type vehicles was a much larger proportion of the total violations issued.

Enforcement Strategies

The responsibilities for truck enforcement vary from State to State. According to the Florida survey, some measure of specialized truck enforcement has been instituted in 42 (88 percent) of the States surveyed. These measures range from merely establishing enforcement priorities for officers on regular patrols to responsibility exclusively for weight enforcement. Forty two States (88 percent) use the selective enforcement concept; 27 States (56 percent) use unmarked cars and six States (13 percent) use minimally marked cars in enforcement areas; half the responding States use aircraft for traffic enforcement although "very few" indicated this method is used strictly for truck enforcement. Twenty of the States (42 percent) reported the use of various other programs, including the reporting of violations to local trucking associations, motor carrier assistance programs, and covert patrol operations. When asked which of the enforcement techniques have proven to be the most successful (success was not defined in the survey), the most frequent response (by 50 percent of the responding States) was selective enforcement programs.

In Arizona, the Department of Public Safety does not handle truck weighing; however, it is responsible for truck inspections. Like most States, Arizona considers the inspection program to be a key part of its enforcement strategy. The inspection program involves approximately 45 people including inspectors at some 15 to 16 port-of-entry locations. Because Arizona is largely a "pass-through" State, port-of-entry inspections play a large role in detecting not only equipment deficiencies but also unqualified drivers, who are felt to be responsible for a disproportionately high number of truck crashes or incidents. Excessive driving hours, DWI violations, and other driver-related infractions are frequently noted.

Arizona also has 13 people whose sole responsibility is truck roadside enforcement. In addition, about 85 percent of its 600 enforcement personnel are qualified to inspect trucks in addition to their other law enforcement responsibilities. Arizona also has a unit that conducts trucking company terminal audits on a periodic basis. Several times a month, concentrated enforcement activities are conducted at various places around the State. State officials work closely with county and other local agencies during these operations. The efforts are not directed only at trucks, however, nor at any specific types of violations. Vehicles are stopped only if there is a reason to stop them.

Arizona has patterned its truck enforcement efforts somewhat after those of California, which has been an originator of many truck enforcement strategies. For many years, the California Highway Patrol (CHP) has maintained a broad-based commercial vehicle safety program. In addition to rules-of-the-road enforcement for all vehicles, which is the primary function of CHP road officers, the CHP responsibilities include commercial vehicle inspections, weight enforcement, mobile road enforcement, participation in major incident response teams and for the Hazardous Waste Strike Force, major incident critiques, hazardous materials vehicle inspections, a commercial corridor program including truck safety maps, and liaison activities with trucking companies and other industry organizations.

Enforcement of the rules-of-the-road and the CHP's commercial vehicle inspection program are designed to reduce crashes resulting from driver errors and equipment deficiencies. Two components of the commercial vehicle enforcement effort are the Critical Item Inspection (CII) Program and the Mobile Road Enforcement Program. Prior to 1977, the commercial vehicle inspection program included a comprehensive 40 minute vehicle inspection. Because of increasing truck traffic, increasing truck crashes related to vehicle deficiencies, and declining personnel resources, the CHP developed the CII Program. The new 15 minute approach limits inspections to only the items that contributed most often to truck-at-fault crashes. The CII fully replaced the 40 minute inspection in 1979. The CII Program also addresses driver hours-of-service limits and vehicle registration laws in addition to the mechanical inspections.

The CII Program has motivated private trucking companies to incorporate the procedures into their maintenance operations. California also was instrumental in establishing the Commercial Vehicle Safety Alliance (CVSA) in 1981 to promote the CII concept and to allow for reciprocity among jurisdictions belonging to CVSA.

CHP officers at nine truck inspection facilities and at 29 platform scale sites put an average of more than 45,000 trucks out of operation each year because of mechanical, overweight, and load securement problems. The Mobile Road Enforcement (MRE) Program uses portable scales to detect overweight vehicles at unannounced locations where truckers would not otherwise encounter an inspection facility. Since 1977, total inspections have more than doubled, from 120,000 in-depth inspections to 249,000 critical item inspections; 55 percent more trucks go through the various inspection facilities, 59 percent more are weighed, and 15 percent more violations are detected at these inspections.

The CHP Hazardous Material Inspection Program involves the annual licensing of hazardous materials transporters and the conduct of truck terminal and off-highway vehicle inspections. The Program was developed to assure compliance with hazardous materials regulations in order to prevent highway leaks and spills that might cause traffic crashes as well as other problems. The CHP has detailed hazardous materials scene management procedures to minimize secondary accidents that might result from such spills.

The CHP also pioneered the Commercial Corridor Concept during a three month trial in late 1980. This program involves concerted driver education and enforcement efforts directed at both automobile and truck drivers and emphasizes driver awareness of dangerous driving practices such as riding in blind spots, tailgating, making unsafe lane changes, failing to use turn signals, and other unsafe driving actions. The pilot program was given at least partial credit for reducing the level of commercial vehicle crashes in the test area from 22 percent to 16 percent of all crashes and for increasing commercial driver citations from three to 11 percent of all citations.

As an extension of the Commercial Corridor Concept, the CHP along with the California Trucking Association (CTA) produced a truck safety map to identify the most hazardous locations for commercial vehicles in Northern California. The concept has since been expanded to other trucking corridors and maps are planned for at least six other areas in the State.

The CHP also has developed an aggressive program of liaison with the trucking industry as well as a public information campaign. Presentations on the Critical Item Inspection program are made to trucking companies around the State, and participation in CTA conferences is encouraged as well as as with other commercial and traffic safety organizations at State, Division, and Area levels. For example, the CHP's Golden Gate Division meets regularly with the Aggregate Haulers' Association and, in the Fresno area, CHP officers ride with truckers and vice versa from time to time to promote a greater understanding of the problems and responsibilities each faces and to improve relations between the two groups. In addition to emphasis on commercial vehicle rules-of-the-road violations and continuing meetings with trucking groups, the CHP's public information campaign includes the preparation of articles for truck and driver publications as well as media releases on crash and citation counts and truck speeds.

Florida's truck enforcement program began in 1984, after numerous complaints from motorists concerning truck violations. The Florida Highway Patrol (FHP) uses both unmarked cars and 10 aircraft to detect traffic law violations in their truck enforcement program. During the past year and a half, the FHP has made 11,530 arrests for various truck violations and issued 3,510 notices for faulty equipment.

The Illinois State Police operate six to eight concentrated roadside inspections a year on routes carrying high volumes of truck traffic. A typical operation might use 30 to 40 inspection officers over a two day period, stopping trucks on a random basis. Illinois also has hazardous materials and vehicle inspection enforcement units. To combat CB use by truckers to avoid the police, the Illinois State Police all have CBs too. To thwart radar detectors, radar units are not turned on until speeding is suspected.

Louisiana State Police participate in a State and County hazardous materials enforcement program. They also make use of roadside inspections and random stops to enforce truck and driving regulations.

Maryland State Police use a special bus and truck patrol to detect moving violations. They use Federal grant funds for truck enforcement on highways where the maximum speed limit is 55 mph.

The Ohio State Highway Patrol does not have any particular unit concentrating on truck enforcement nor any special program targeted on truck safety. Instead, enforcement efforts are for all vehicle types and involve all troopers.

Virginia State Police have a special Truck and Bus (TAB) enforcement program in which unmarked sports cars are used to detect commercial vehicle traffic violations. These special vehicles are in addition to the 27 percent of its fleet that is unmarked. Because over 20 percent of the drivers cited in Virginia for violating 55 mph posted speed limits are truck drivers, trucks are targeted for selective enforcement. Airplanes are used to detect violators but not to document the infraction, which are handled by officers on the ground who are alerted by the aircraft. Virginia was the first State to implement a regulation prohibiting the use of radar detectors. Only two other jurisdictions, Connecticut and the District of Columbia, have adopted similar measures .

The Washington State Patrol truck enforcement activities are very similar to those of the Illinois State Police. Its "55 team" enforces speeding regulations for all drivers and 48 hour concentrated enforcement efforts are conducted at key ports-of-entry. A Commercial Vehicle Bureau handles inspections, size, weight, load regulations, and hazardous materials. The State Patrol also uses CB radios to reduce their use by truckers to avoid detection.

Available information shows that most states report they have some type of special truck enforcement program. At least half of the jurisdictions feel that selective enforcement is the most effective enforcement technique, however, data were not provided to confirm this perception.

Hindrances to Effective Enforcement

Most of the State police agencies contacted for this study felt that truck traffic law enforcement was limited because personnel and funds were typically dedicated to other uses. Some of the agencies interviewed have been more successful than others in getting additional enforcement personnel and/or in getting existing resources reallocated to truck-related activities. Some of the success is attributed to public pressure on elected officials in those states to "do something" about the perceived truck safety problem. Other agencies' success has been due to efforts by enforcement officials to educate both the public and state legislatures about the perceived problem and what could be done to reduce it.

Illinois State Police indicate that reciprocity for traffic violations among States, even those states who are members of the Driver License Compact, does not seem to work with many states, and out-of-State citations are often ignored. This allows drivers to continue to drive with multiple convictions that would otherwise be cause for some type of licensing action.

The Maryland State Police (MSP) conducted a six month study of radar detector use in the last half of 1985. Of the 6,000 motorists caught for speeding by use of VASCAR (an electronic speed measurement system that uses time and distance measurements), 40 percent were observed to have detectors in their vehicles. However, 1,200 of the 6,000 (20 percent) violators were truck drivers, and 85 percent of them had detectors visible. To get more complete data on the use of detectors by truckers, the MSP observed trucks passing through scale houses and at truck stops. There were visible detectors in 17 percent of the trucks at the scales. At truck stops, which are frequented more by long-haul truckers, 81 percent of the trucks observed had detectors in sight. The MSP are now collecting the same information about trucks involved in crashes.

Besides the use of the detectors to avoid enforcement, another reported problem for enforcement, at least in Virginia, is that the police must observe the radar detector in use; possession alone is not illegal. Unlike CB radios, radar detectors, according to some enforcement officers, have no speeding deterrent effect. The police contend the device may predispose persons to speed.

Most state police agencies interviewed would opt for more personnel to continue and expand existing enforcement efforts if given a choice of added resources. Arizona Department of Public Safety would add inspectors, expand the roadside special enforcement efforts and terminal audits, give more support to the 55 mph maximum speed limit, and change legislation to increase the level of fines. Illinois State Police report they would hire more people for truck enforcement.

Louisiana State Police would dedicate more personnel to enforcement, to truck driver education, and to safety awareness programs. Maryland, too, would increase its enforcement personnel, especially at the "worker" level, with more roving portable scale crews and more personnel actually doing enforcement. Maryland has a radar detector prohibition bill pending. And the Maryland State Highway Administration recommends that large trucks be prohibited from the left-most lane of all eight lane (or more) freeways.

The Ohio State Highway Patrol would like to direct more activities toward hazardous materials transportation. They are working toward developing a cooperative relationship with trucking companies. Virginia State Police would increase enforcement of the rules-of-the-road for all drivers. The Washington State Patrol also would put more personnel into enforcement. They believe that police presence is the single most effective enforcement technique. They would put more people at port-of-entry locations and use more portable weighing devices.

Limited data are available validating the effectiveness of one enforcement strategy compared to another. Accordingly, before significantly more personnel are assigned to enforcement, better information on the effectiveness of various enforcement strategies would be helpful in determining which strategy to use. This is not to say that more officers are not needed, but there still is no conclusive data to show the best use of existing personnel. One potential solution is to use civilian inspectors, as Michigan is now doing, along with a police officer. This procedure is less costly than having all the inspections done by uniformed officers. Another is the use of California's Critical Item Inspection procedures which has been proven to be a more cost effective use of personnel.

Industry and Public Perspectives

Industry Associations and Safety Organizations

Comments to the NHTSA Docket 85-17, opened for this study, were reviewed for relevant information on safe truck driver behaviors and enforcement issues. Among the comments were:

- Insurance Institute for Highway Safety (IIHS) in excerpts from their Status Reports pointed out that representatives of the trucking industry in testimony before the Senate Commerce Committee have called for increased law enforcement and improvements in commercial vehicle driver training and licensing. IIHS also reported the results of a survey of 1084 adults, the majority of whom were said to be in favor of national licensing for truck drivers.

- New York State Automobile Association recommended that a national licensing procedure for heavy truck drivers be established.

- American Trucking Associations cited the need for improvements in truck driver driving behaviors, traffic law enforcement and truck driver licensing. The following was recommended: a uniform national commercial driver license issued by state licensing agencies and classified by the type of vehicle the driver is qualified to drive; a unique personal identifier and process to assure that an individual has only one driver license; uniform standards for testing knowledge of traffic laws and rules-of-the-road, knowledge of vehicles and vehicle inspection procedures, and skill in handling the vehicle; a national commercial vehicle driver license register; and, a requirement that uniform information about traffic violations be forwarded to the license issuing state to ensure one complete record for a commercial driver.

- American Automobile Association outlined a detailed plan for establishing a national standard for a combination unit truck driver license. The purpose of the license would be to eliminate high risk drivers, those that are poorly trained to drive this special class of vehicle, and those with multiple licenses or excessive traffic violations or crashes. The national standard would establish driver qualifications to obtain a driver license, would establish a central driver license file, would require states to report serious crashes and violations to state of record, and would allow the issuing state to suspend or revoke the license.

- Motor Vehicle Manufacturers Association supplied a copy of "Commercial Vehicle Safety: A report to the Secretary of Transportation" by the National Highway Safety Advisory Committee. The report recommends, among other things, that truck driver training and licensing be improved and better tailored to the operational requirements of commercial vehicles. In addition, they supplied a copy of "New Directions in Commercial Vehicle Safety" which contains among its recommendations: improving the quality of truck driver training, testing and certification, and promoting the goals of the Professional Truck Driver Institute of America; enhancing the NDR to weed-out drivers with bad safety records; and, adopting a classified truck driver license nationwide.

Truck Drivers

A recent survey conducted by the University of North Carolina at Charlotte was used to obtain truck drivers' perspectives relative to law enforcement activities and safety problems related to heavy trucks. The 20 drivers who completed the survey ranged in age from 25 to 68 and had from four to 50 years truck driving experience. The split between company drivers and owner-operators was approximately equal. Because the number of drivers interviewed was small, the following results should be viewed as an indicative, rather than statistically valid, sampling of all truck drivers views.

The majority of the drivers interviewed felt there would be fewer problems with heavy trucks if better maintenance was performed and drivers were properly trained. They also felt that crashes involving trucks and smaller vehicles are the fault of the truck driver only about half the time. This was qualified, however, by the observation that very few truck crashes occur due to mechanical failure, i.e., it is usually the fault of one or the other driver involved.

Very few of the truck drivers surveyed reported being cited for a moving violation during the last year. However, about half of them did know other drivers who had been cited. The most frequent violation reported was speeding. When asked if they know of any special enforcement efforts currently being employed by police, the general answer was no. However, some drivers indicated they were aware of police efforts that were concentrated more heavily in certain trucking corridors.

Radar detectors were used by about half of the truck drivers interviewed. When asked to estimate the use of detectors by truck drivers, most felt that between 70 to 90 percent of truck drivers use detectors. CB radios were used by about 75 percent of the drivers to keep track of the police. This was also the percentage estimate of use by all drivers at some time. However, the truckers also stated that too much "garbage" is on the CB for it to be used effectively to track the police all of the time.

The majority of drivers who reported they had changed routes to avoid enforcement only did so to avoid the authorities in charge of weight and vehicle inspection. No driver reported actually changing routes to avoid traffic law enforcement efforts.

The majority of drivers interviewed felt that in order to reduce the number and severity of heavy truck crashes there needs to be better drug and alcohol enforcement and improved driver qualification and licensing. The drug and alcohol problem was a major concern to many of the drivers, who felt that this problem is giving the industry as a whole a bad name.

Inadequate driver qualification and licensing was considered by many of the truck drivers interviewed to be the reason for a lot of crashes. Most of the drivers interviewed had obtained their driving skills through "on-the-road" training. They were very critical of driving schools and felt that most schools do not provide adequate training. One solution that was offered is to require new drivers to ride with an experienced driver for a number of months until sufficient experience is obtained.

Some of the drivers interviewed felt that there is a problem with some drivers having multiple licenses and using a different one for each new citation. They felt this leads to drivers being on the road who would have been suspended from driving if they had only one license. (In response to the requirements of the Commercial Motor Vehicle Safety Act of 1986, The Federal Highway Administration is currently preparing a commercial driver licensing standard requiring that operators of commercial motor vehicles possess only a single driver's license.)

Other problems reported by the drivers interviewed were driver fatigue, unsafe driving habits especially in bad weather, and the lack of a good maintenance program by some companies and drivers. A few drivers reported that inadequate guide signing, especially in advance of complicated interchanges, creates unnecessary safety hazards even for the most experienced drivers.

Trucking Companies

Several trucking companies were contacted to determine their perceptions and roles in law enforcement and safety issues related to the trucking industry. The main issues covered were truck driver qualifications and the safety programs provided by the companies.

A common company-specified requirement is that a driver must have at least one year of interstate driving experience before he/she will be hired. A prospective driver also must pass the company road test. All the companies reported that drivers who were cited for violations are required to report the violations to the safety department of the company. Disciplinary action could then be taken depending on the severity of the violation. The companies also reported that they review State driver records to determine if any violations had not been reported by the drivers.

Another common item of concern to the companies are driver logs and the accuracy of the logs. The logs are filed by the truck drivers with the safety department. The safety department reviews the logs to verify that no violation of driving time has taken place. Again, such a violation may result in disciplinary action which could include suspension.

Trucking companies also were concerned with the failure of truck driver training schools to adequately train a driver. Several of the North Carolina companies did suggest that at least one school does provide excellent training that results in adequately prepared drivers. The program provided by the school is eight weeks in length and consists of 30 percent classroom training, 35 percent controlled field training, and 35 percent road training. Each student must be at least 18 years old and have a valid driver license. The school emphasizes all phases of trucking from maintenance of the truck and trailer to safety regulations and laws.

SUMMARY

There is a growing perception among traffic law enforcement officials that truck drivers' adherence to traffic safety laws -- notably speeding, following too close, and improper lane changing -- is bad and getting worse. However, these same enforcement agencies do not collect definitive data to either substantiate or refute that perception. There is at least some indication that the compliance rate of heavy truck drivers with traffic safety laws may be no better or worse than the compliance rates of drivers of other types of vehicles.

Police traffic law violation/citation information is not uniformly collected among the states. In many cases, information related to heavy truck safety equipment deficiency violations and/or violations of truck size and weight limits is all that can be tabulated from state files. While these types of violations have a bearing on truck safety, they do not characterize the manner in which trucks are driven in the same context as do "moving" violations such as speeding or following too close.

Specific information about the proportion of traffic law violations (i.e., "moving" violations) that are attributable to truck drivers is not uniformly available. In addition, there is no way of knowing whether the amount of enforcement activity directed towards "moving" violations by heavy truck drivers is more or less than what is warranted based on some type of objective index such as percent of traffic volume or percent of total accidents. Accordingly, some type of systematic data collection effort would be necessary before questions about whether truck drivers violate traffic laws more frequently than do drivers of other types of vehicles, or whether more enforcement activity needs to be directed towards heavy trucks can be addressed.

The techniques/strategies used by police to enforce truck driver adherence with traffic laws vary widely, from no special techniques to innovative techniques designed to counteract the almost universal use of radar detectors and CB radios by truck drivers. There are divergent opinions as to which techniques are most effective and, as before, there are no data available to substantiate the advantages of one technique compared to another. There is universal agreement among traffic law enforcement officials, however, that the widespread use of radar detectors, if it does not encourage speeding, at least facilitates it.

The Department of Transportation is moving aggressively to implement the Commercial Motor Vehicle Safety Act of 1986. This legislation should improve the safe operation of trucks because it would prevent truck drivers from continuing to drive on a second license after the first license has been suspended or revoked. The act will also improve the record keeping ability of the States.

Finally, traffic law enforcement officials generally agree that a combination of actions are necessary to achieve acceptable compliance rates by truck drivers with traffic safety laws. These include, but are not limited to: better training and more professionalism among truck drivers; an enhanced ability to sanction drivers who are repeat offenders, especially in cases where those offenses are committed in more than one state; and substantive fine structures for offenses to increase the deterrence effect associated with being convicted of a traffic law violation. There also was general agreement that better communication within the traffic law enforcement community is necessary to convey information relative to enforcement strategies that are effective, as well as information relative to the overall effectiveness in reducing violations and accidents attributable to various enforcement techniques.

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Appendix A

Summary of Comments
Submitted to
"Heavy Truck Safety and Truck Occupant Crash Protection"
Docket No. 85-17, Notice 1

001 Insurance Institute for Highway Safety (IIHS)

Excerpts from IIH's Status Reports were supplied. They pointed out that representatives of the trucking industry in testimony before the Senate Commerce Committee have called for increased law enforcement and improvements in commercial vehicle driver training and licensing.

Representatives of associations such as the ATA and the International Brotherhood of Teamsters voiced concern over the deterioration of highway safety caused by deregulation. Shortcomings of the BMCS data were also reported in the excerpts as were details of reorganization of BMCS. Problems faced by trucking industry in obtaining insurance and the high cost of insurance were detailed.

Representatives of the Independent Insurance Agents of America urged better enforcement of insurance requirements for truckers. The Alliance for a Motor Vehicle Administration Telecommunications (AMVAT), a group comprising of American Association of Motor Vehicle Administrators together with other agencies and organizations, testified that they are developing an on-line drivers' licensing system to replace NDR. This system would use digitized finger prints or retinal imagery as keys to identify drivers.

002 New York State Automobile Association

The New York State Automobile Association submitted a report entitled: "Truck Safety Shortcomings". It details problems in the areas of braking systems, excessive jackknifing, truck aggressivity and splash and spray protection systems, truck driver driving behavior, and truck inspections. The following recommendations were made to improve truck performance:

- Promulgate rigorous truck brake performance standards which would bring truck stopping distances close to those of cars.
- Make it crime to disconnect front brakes.
- Promote research aimed at substantially reducing jackknifing. Mandate the use of retrofit devices to reduce jackknifing.
- Promulgate truck front and rear bumpers standards to provide optimum underride/override protection to autos.
- Eliminate delays in making splash and spray equipment standard equipment on trucks.
- Establish national licensing procedure for heavy truck drivers.
- Establish regular, stringent and effective truck inspection program in New York State.
- New York and neighboring States should participate in CVSA.

003 Letter from Peter Hafner, Exec. Director, American Independent Truckers Association Inc. (AITA).

Mr. Hafner suggests that car drivers need to be better informed how to drive around trucks. They should not pass and then pull in front of trucks. Truck crashworthiness should be improved by using roof support beams and middle windshield supports. Airbag technology should be considered for trucks.

004 Unsigned Letter

Suggests that in non-metropolitan areas, trucks be prohibited from following an automobile ahead closer than 1/2 the truck length although they should be allowed to follow other trucks at lesser distances. Automobiles should be prohibited from entering the safety zone between a truck and a vehicle ahead. Also suggests that highway speeds be increased to their design speed of 75 mph.

005 Comments of American Trucking Association, Inc. (ATA)

Comments deal with the role of truck drivers in accident causation. Quote National Safety Council Statistics that driver error was a factor in 72.1 percent of all accidents. Cites the need for improvements in truck driver driving behavior, traffic law enforcement and truck driver licensing. ATA recommended the following:

- A national uniform classified licensing system for commercial drivers.
- A national commercial vehicle driver license register with a unique identifier that all states use.
- A system whereby traffic violations occurring in any state would be forwarded to the State issuing the license and that appropriate sanctions be applied for excessive violations.

006 American Trucking Association, Inc. (ATA)

The ATA Engineering Department and the Technical Advising Group (TAG) submitted the following comments relative to brakes, stability and handling, crashworthiness and aggressivity. Among the points raised were the following:

- There is a lack of rational cost-effective performance standards requirement for heavy truck brakes.
- Contends that limit condition stopping performance tests are spurious.
- In the near future, NHTSA should support TTBRG to obtain better brake componentry to eliminate compatibility problems.
- Maintainable, not overly complex brake systems should be a primary goal.
- NHTSA should consider supporting further compatibility tests between vehicles with different kinds of brakes.
- Brake maintenance hampered by inability to obtain replacement brake linings with torque characteristics equivalent to OEM equipment.
- NHTSA should study the effects of various tire sizes on the AL factor in brake balance.
- NHTSA should study the influences of sliding 5th wheels and 5th wheel height on brake balance and vehicle stability during braking.
- NHTSA should study the feasibility of having a common brake activation and warning system.
- NHTSA should study -- as a long range project -- the possibility of designing an "intelligent" or "adaptive" braking system.

- ATA is concerned about the handling and stability research done to date because of questions about the underlying assumptions used and how the information can be practically translated in equipment designs.
- On-board instrumentation should be considered to feedback information to the driver to aid his driving.
- Size and weights change deliberations should not be "unlinked" from their effects on stability.
- Crashworthiness improvement should focus on defining crash forces and convincing drivers to use restraints.
- The concept of cab "fireworthiness" performance should be explored - making a cab capable of safely protecting an occupant in a fire for a specific period of time.
- Underride needs no further study. Present guards are adequate.
- The TMC S.4 Study group has set tentative future performance targets for cabs to have a life of 10 years or 1,000,000 miles and maintenance cost on 70% of today's cost. The occupant space should be inviolable in crashes and fires. Cab design should expand outward visibility and simplify maintenance.
- Cab occupants should be restrained by a 3 point belt or shoulder harness system with locking retractor. Belt harnesses should be releasable by drivers wearing arctic mittens and be operable under the weight of a 95% male driver.
- Cab interior design should prevent occupant contact with interior during rollover etc.
- Use Swedish Road Safety Office test as a design guide to ensure crashworthiness of cabs.
- Use electrical kill switches to disable electrical systems in the event of collision. In the event of fire, the cab should withstand inside temperature of 115°F for 30 minutes. Use nonflammable, non-toxic materials inside cabs.
- Provide means to restrain occupant's personal effects.
- Provide non-toxic automatic/manual fire suppressent system in the cab.
- Design cabs so that they can be readily maintained using available skills and tools.
- Design cabs to reduce air drag and to keep mirrors and glasses clean and suppress splash and spray.
- Factor in maintainability as a cab design goal.
- Various other factors such as durability of cabs, human factors (internal cab environment and visibility) requirements were discussed.

<u>007 General Motors Corporation (GM)</u>

Copies of slides prepared by GM for a meeting with NHTSA staff on the topic of braking and stability were provided. The following is a summary of the information contained in the slides.

- GM analyzes handling to ensure optimum control response and on-center handling. Calculations are verified by running full scale tests; some very close to rollover limit.
- GM's body builder manual gives formulae and sample calculations to calculate axle loads and c.g. height.
- GM feels that they may have success in reducing weight of cab and other superstructure elements. Significant reduction in C. G. height has to come from the C. G. of cargo. Air spring suspensions are helpful in this regard but they do not expect a reduction in tire diameters in the near future.
- Wider trailers expand the stability window, however, there is little incentive to widen tractor track width. The benefits in developing and introducing single tires may be outweighed by the negative aspects. Believes that greater gains can be achieved through continuous upgrading of driver awareness of truck dynamics problem.
- Some warning devices like tire pressure monitors are under development at GM while some, like vision enhancement devices and mutual detection devices, are in the experimental stage. The large number of parameters involved in rollover makes it difficult to write an algorithm or develop a device to warn of impending rollover.
- There is not much information available about the driver actions in the vehicle control feedback loop. Investigation of how the driver interprets vehicle feed back and how he responds with "new" corrective action would be helpful in objectively specifying handling characteristics of trucks and trailers.
- GM feels that a viable tractor/trailer compatibility standard can be written if due consideration is paid to vehicle operating environment, component performance standards and vehicle performance. R & D work needed can be done through the development of analytic models and exercising them to conduct sensitivity studies.
- GM has not worked directly with any trailer manufacturer in brake compatibility issue. They have worked with customers and made recommendations to improve compatibility. They can also test combination-unit brake system at the customer's request.
- GM designs brake system components to meet system performance criteria. They feel that brake system parts should be replaced with OEM parts by part number.
- GM trucks and combination-units with air brakes built in the USA do not meet the requirements of EEC 71/320 regulations. They feel that EEC system is unnecessarily complex without the complexity adding value.

- GM continually evaluates options and systems to improve performance, notably :front brake limit devices, bobtail features, new linings, brake sizing by gross axle weight rating (GAWR), and structural performance tests.
- GM is moving to 5.5 inch slack adjuster length. They do supply automatic slack adjusters at the customer's request. They have had no feedback concerning reliability problems of auto-slack adjusters.
- Customers prefer low power brake torque on front axles.
- GM offered AC and EATON anti-lock systems in the early 1970's. AC system was standard equipment until 1986 when it was discontinued due to lack of interest and discontinuation of its manufacture. Wheel lock control is a good system and will add to safety. It will be better accepted as the field becomes more used to electronic components.
- GM has done very little evaluation of load sensing brake systems on air brake vehicles. European systems are complicated and still have significant shortcomings. To their knowledge, no such system is available in the USA.
- Brake system features will sell if they can provide a demonstrable and measurable reduction in the cost of ownership.

<u>008 American Automobile Association (AAA)</u>

The AAA outlined a detailed plan for establishing a national standard for for a combination unit truck driver's license. The purpose of the license would be to eliminate high risk drivers, those that are ill-trained to drive this special class of vehicle, and those with multiple licenses, or excessive traffic violations and/or accidents. They state that neither the National Driver Register (NDR) nor the Driver License Compact (DLC) are effective in this regard since both have inherent weaknesses. Many states do not have classified licenses for truck drivers, rendering the NDR ineffective while many states do not belong to the DLC, rendering it ineffective. The AAA proposal is as follows:

* Qualifications to obtain a national truck driver's license (NTDL)
  - Age 21 unless applicant has completed an approved truck driver training course, then age 18.
  - Pass a written exam.
  - Pass BMCS physical qualification requirements.
  - Applicant must certify that he/she does not have a suspended or revoked license and that in previous 3 years applicant has not had any traffic convictions resulting in a fatality nor any convictions for DWI or leaving the scene of a fatal or injury accident.
* "Grandfathering"
  - Current holders of valid commercial driver's licenses would have one year to apply for a NTDL. It would automatically be issued if they had been driving the vehicle for the past 3 years, and could meet all the other requirements.
* License Check with a central file
  - States would continue to issue licenses but would check with a central file for duplicates, suspensions,and revocations.

* Violations reported to issuing state
  - All states would be required to report serious accidents and traffic violations involving a NTDL holder to the state issuing the NTDL.
* Suspensions revocations and retrievals
  - Each state could suspend, revoke NTDL's it issued. Appeals procedures would be established. These would be reported and tracked in the central file.

009 Nothing logged

010 Associate Administrator, Research and Development

Cover letter from Associate Administrator, NHTSA Research and Development to Office of Chief Counsel, DOT, submitting to the docket material supplied by the motor vehicle manufacturers Association (MVMA).

011 PACCAR, Inc.

PACCAR recommended the following:

. All occupant protection measures must be based on real-world truck accident research.
. PACCAR testing is limited to compliance testing. Full scale barrier tests are not cost effective except to evaluate redirection ability of median barriers.
. PACCAR encourages truck exposure research and detailed accident investigation.
. They consider the possibility of designing trucks to deflect oncoming cars or stationary barriers worthy of further study.
. Current brakes are simple, reliable, easily maintained and perform predictably under different operating conditions. Newer brake designs suffer from various shortcomings.
. PACCAR is preparing to evaluate a load sensing brake proportioning system based on air pressure sensing in an air suspension system.

. PACCAR is completing work on a full vehicle tilt table.
. They support efforts to establish and enforce operator certification programs and tracking operator performance.

012 Motor Vehicle Manufacturers Association (MVMA)

Letter from F.W. Bowditch, V.P. of Technical Affairs, submitting 28 MVMA sponsored or written reports and papers dated from 1976 to 1985.

013 Motor Vehicle Manufacturers Association (MVMA) supplied copy of : "Analysis of Truck and Combination-Unit Accident Data", CALSPAN, June, 1976.

The authors of the report studied the validity of 21 hypotheses pertaining to accident characteristics, fatalities, accident rates and other miscellaneous hypotheses. They concluded that:

- The presence of a truck in a multi-vehicle accident substantially increases the likelihood of a fatality.
- Because of their greater exposure, trucks are likely to have more accident involvements than cars, but there is no clear proof that the accident rates for trucks are greater than that for cars.
- In a car-truck accident, there is no definite connection in the effects of truck weight changes on the likelihood of fatality in the car.

014 Motor Vehicle Manufacturers Association (MVMA)

Supplied a copy of : "Analysis of Tractor-trailer and Large Accident Data", SWRI, June, 1976. The author analyzed 1974 Texas State collision data and 1975 truck accident data from two defined areas of California in order to review, evaluate and critique twenty-one hypotheses pertaining to large truck safety. He concluded that:

- There is a need for more in-depth large truck accident studies.
- Large trucks are over involved in accidents, particularly in fatal crashes, as compared to small trucks and passenger cars.
- Occupant injury severity in cars or trucks involved in single-vehicle accidents are almost the same.
- It is more dangerous to be in a car in a car-large truck collision than in a truck. Truckers are more at fault in these accidents.
- Trucks rear end cars more often than cars rear end trucks.
- Safety defects in trucks are more frequently reported than cars. Major truck defects include brakes, lights and tires.
- There is a need to develop a better exposure measure than ton-mile.

015 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Car-Truck Fatal Accidents in Michigan and Texas", HSRI, October, 1977.

Fatal accidents for Michigan (1972-76) and Texas (1975-76) for cases of passenger cars rear-ending or side-impacting a large truck or a combination-unit were examined.

The authors concluded that the annual number of such accidents was at least 450 and might reach 570, and 90% of rear-ends and 75% of side impacts resulted in underride. Such accidents usually occurred at night on straight rural roads, most involved drivers were males. Drinking involvement was about the same degree found in all accidents. Relative impact speeds usually exceeded 30 mph in the cases examined.

The authors concluded that underride guards with energy absorbing capability and enhanced conspicuity of truck and trailer would reduce but not eliminate rear-end and side-impact accidents between passenger cars and large trucks or truck trailers.

016 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Analysis of Heavy Truck Accident Data", CALSPAN, 1978.

Data available in the CALSPAN TLAS level 2 file regarding heavy truck involvement from 1969 to 1975 were tabulated and analyzed. Data showed that combination-unit trucks, single-unit trucks and tractors without trailers were most often the striking vehicles in accidents where they were involved. Given a rear end collision involving a combination-unit truck, the combination unit truck was more than twice as likely as the other vehicle to have been the striking vehicle. It was also found that the occupant of combination-unit trucks involved in multi-vehicle accidents as the striking vehicle had a lower risk of injury that the occupant of other types of vehicles involved as the striking vehicle.

017 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Analysis of Heavy Truck Underride Accident Data", CALPSAN, 1978.

Level 2 data of the CALSPAN Tri-Level Accident Study (TLAS) collected during the period 1969 to 1975 in an eight-county area of western New York were analyzed. The analysis revealed that:

- Less that 2 percent of all accidents resulted in a potential underride situation.
- Collisions involving underride resulted in a greater proportion of injuries and fatalities than non-underride collisions.
- An estimated 8.2 percent of auto-heavy truck collisions involved underride damage. Only about 3 percent of the accidents involved severe underride damage.
- Classification of accidents based on components of CDC were insufficient to identify all collisions involving underride damage though it was sufficient for identifying collisions involving extensive underride damage. It was recommended that future data pertaining to potential underrides include a code to indicate the occurrence of underride.
- A uniform definition of underride needs to be developed which would emphasize the role of underride in the collision, i.e., it would separate extremely severe underrides from those for which underride damage was incidental to the outcome of the accident.

018 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Comparative Analysis of Accident Data in The State of Michigan", Wayne State University, 1979.

Historical accident and exposure data for the State of Michigan were analyzed. Analysis revealed that :

- Trucks had a higher rate of fatal and property damage accidents than non-trucks, a lower rate than others for injury causing accidents.
- In almost all categories, PPVs (Pickups, Panels and Vans) and single-unit trucks had a higher accident rate than non-trucks while combination-unit trucks had a higher rate for fatal accidents only.

- Single-unit trucks has the highest accident record, followed by PPVs and combination-unit trucks.

A number of recommendations for future research were also made.

019 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Comparison of Michigan Fatal and Non-Fatal Car-Into-Truck Accidents," HSRI, 1979.

A random sample of 100 non-fatal passenger car rear end or side impacts on a large truck or truck trailer in the State of Michigan was compared with 94 fatal car-into-truck accidents in Michigan during 1972-76. The authors found:

- In non-fatal accidents, underride occurs infrequently and when it does, it is usually of mild or minor degree.
- Non-fatal crashes occurred mostly in day time, on urban roads and intersections, at relative crash speeds averaging 10 mph. Cars often crashed into trucks and trailers of a design that prevents underrides.
- Fatal crashes occurred mostly at night on rural roads at impact speeds averaging 35 mph.

020 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Analysis of Truck Accident and Exposure Information - Phase I Report," HSRI, 1979.

Outlines HSRI's plans for collecting and analyzing state and national level accident and exposure data.

021 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Accidents and Nighttime Conspicuity of Trucks," HSRI, 1979.

A study of 1977 FARS data revealed that fatal car-into-truck collisions occur more frequently at night.

A review of literature in nighttime conspicuity and effects of retroreflectorization confirmed that increasing the size and contrast of targets enhanced conspicuity.

Experiments with paid volunteers revealed that the subjects saw the standard semi-trailer at a distance of 300-400 ft with low beam headlights. When additional retroreflective material was mounted on the trailer exterior, sight distance increased to 1000 ft. This indicated that eye fixation times are a useful measure in conspicuity investigations.

022 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Combination Vehicle 5 Year Accident Experience," HSRI, 1980.

Analyzed FARS and Texas data from 1975-1979. Many tabular presentations of information in those two data sets are provided.

023 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "The Affect of Cab Style on the Accident Exposure of Heavy Trucks," HSRI, 1981.

Compared operational characteristics and occupant injury experience in trucks and tractors of cabover and conventional cab designs. Concluded that injury and fatality rates based on BMCS data is not significantly different for the two designs. However, fatality rates derived from FARS and TIUS indicated that occupants of cabover design trucks were at a slightly higher risk than occupants of conventional cab design.

024 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "A Comparison of Accident Characteristics and rates for Combination Vehicles with one or Two Trailers", HSRI, 1981.

Data from BMCS and TIUS were analyzed to obtain accident involvement rates for combination units with single trailers and those with more than one trailer.

Overall, the accident involvement rate for doubles and singles was found to be nearly the same, although there were substantial difference in the types of accidents for each vehicle type. A log-linear model was used to analyze the involvement rates of combination vehicles. Vehicle configuration, trip length and trailer type were included in the analysis. Results from the model indicated that all pairwise interactions were significant.

The authors suggest that a more detailed accident analysis be performed to identify a factor or a group of factors frequently present in various accident types associated with singles and doubles. They stress the need for collecting more information concerning road class, time and driver factors to complete the data set.

025 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Measurements of the Longitudinal and Lateral Traction Properties of Truck Tires," HSRI, 1981.

Catalog information pertaining to shear force properties of specific truck tires.

026 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: Steering and Suspension Systems", HSRI 1981.

Provides information pertaining to mechanical properties of steering and suspension systems used on heavy trucks.

027 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Steering and Suspension Systems," HSRI, 1981.

Detailed information on the circumstances and consequences of heavy-truck accidents contained in the Collision Performance and Injury Report (CPIR-B) were analyzed. Data in the CPIR-B were collected from late 1960's to late 1970's.

The analysis of FARS 1979 data showed that rollover and ejection were associated with heavy-truck occupant fatalities about twice as frequently as for passenger car occupant fatalities. A panel of 6 experts reviewed 41 in-depth cases to assess the possible effectiveness of restraint use and the contribution of rollover and ejection to the fatal injuries. The panel's responses indicated that belt use was expected to be particularly effective in preventing fatalities resulting from occupant ejection.

A lower rate of ejection for 1972 and post 1972 model heavy trucks as compared to the pre 1972 heavy trucks suggested that FMVSS 206 was effective.

028 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Fact Book on Combination Vehicles in Fatal Accidents, 1975-1981," HSRI, 1983.

FARS data for years 1975 to 1981 are analyzed and statistical data about combination vehicle in fatal accidents is presented.

- Combination truck fatal accident involvement rates increased from 5.2 percent to 7.0 percent in 1979. This fell to 6.1 percent in 1980 and increased to 6.3 percent in 1981. From 1975 to 1981, 30,000 people (8.9 percent of all accident fatalities) were killed in 25,000 accidents involving combination vehicles. About 6,000 of these were occupants of combination vehicles.
- 77 percent of combination truck fatal accidents involved two or more vehicles as compared to 57 percent for both passenger cars and all other trucks.
- Multi-vehicle accidents involving combination trucks and small vehicles are much more likely to be fatal to the occupant of the smaller vehicle.
- 72 percent of combination truck fatal accidents involvements are on rural highways. About 73 percent of fatal involvements take place on "high speed" (55 mph speed limit) roadways.
- About 45 percent of fatal involvements take place between 6 P.M. and 6 am. 5 percent of combination vehicles involved in fatal accidents were reported to have mechanical defects mainly in tire, wheel and brake systems. Less than 5 percent of combination vehicle drivers in fatal accidents were involved with alcohol.
- Rollovers were involved in 56 percent of fatal combination truck occupant fatalities. One-third of the fatally injured occupants were totally or partially ejected. Surviving occupants of combination vehicles involved in fatal accidents wore safety belts twice as often as the fatalities.

029 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Trucking and Stability of Multi-Unit Truck Combinations," UMTRI, 1984.

Analysis methods for evaluating the low-speed tracking and high-speed maneuvering capabilities with drawbar steering systems are presented. Analysis indicates that dollies with drawbar steering systems tend to have large amounts of rearward amplification in high-speed maneuvers. Trailer wheels that steer in response to draw bar angles provide good tracking but reduce articulation stability. Authors suggest that innovative dolly concepts and hitching arrangements are reasonable areas for future research aimed at reducing rearward amplification without incurring the penalty of poor low-speed off tracking performance.

030 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Issues Related to the Usage of a Tilt Table for Measuring The Roll Stability Characteristics of Heavy Duty Truck Combinations," UMTRI, 1984.

Reports on the issues related to the use of a tilt-table to measure the roll stability of heavy-duty trucks. The questions addressed were:

- What is the relationship between the static stability measure obtained in a tilt-table and dynamic rollover threshold in realistic highway conditions?
- How can a tilt-table be applied in support of design and development of a commercial vehicle?
- How is the tilt-table used in different countries?
- Can the Canadian tilt-table be used or does it have to be enhanced to meet the demands of US?. Is it necessary to build a tilt-table at UMTRI?

Past literature was reviewed to provide answers to the above questions. A conceptual design for an UMTRI tilt-table is presented. Cost of the device was estimated at $95,000 in 1985/86 dollars. Time to erect the device would be 8 months and the cost per test was estimated to be about $800.

031 Motor Vehicle Manufacturers Association (MVMA) supplied a copy of: "Trucks Involved in Fatal Accidents, 1982," UMTRI, 1984.

One-way frequencies for all the available variables in the UMTRI 1982 file combining FARS and BMCS data are presented:

- A total of 4718 medium/heavy trucks were involved in fatal accidents in 1982. Of these 1265 (26.8 percent) were single-unit trucks, and 3434 (72.8 percent) were combination-unit trucks.
- Of single-unit trucks, 86 (1.8 percent of the total sample) had full trailers, 1254 had no trailers and 75 (1.6 percent of total sample) had some other type of trailer.
- 3140 (66.6 percent) of the tractors had a semi-trailer, 134(2.8 percent) were bobtail, 130 (2.8 percent) had a semi and a full trailer, 17 (0.4 percent) had a single, non-semi trailer.
- 3280 (69.5 percent) of the 4718 trucks were operated by interstate carriers, 1107 (23.5 percent) by intra-state only carriers and 331 (7.0 percent) were either owned by government, used for daily rental or had unknown ownership.
- For hire carriers accounted for 2416 (51.2 percent) of the involved vehicle and private carriers for 2023 (42.9 percent).

032 Misscoded:: same as 031.

033 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Truck-Other Fatal Accidents 1980-82," UMTRI, 1985.

The UMTRI data for trucks involved in fatal accidents with other vehicles, between 1980-82 was analyzed to provide one-way frequencies for all the variables.

- 5056 medium/heavy trucks were involved in fatal accidents in 1980, 5244 in 1981, and 4718 in 1982.
- Over the three years, of the 15,018 medium/heavy trucks involved in fatal accidents, 4062 (27 percent) were single-unit trucks and 10,844 (72.2 percent) were combination-unit trucks.
- Of the single-unit trucks, 3632 had no trailers, 226 had a full trailer, 158 had some other kind of trailer, and 1 had two full trailers.
- Of the 10,844 tractors, 9917 had a semi-trailer, 446 had semi and a full trailer, 4 had three trailers, and 383 were bobtails.
- Of the 15,018 trucks, 9811 were operated by interstate carriers, 3715 by intra-state only carriers, and the rest 1492 were either owned by government entities, used for daily rental or had unknown ownership.
- Other univariate tables are presented.

034 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Truck-Truck Fatal Accidents, 1980-82, UMTRI, 1985.

Authors reported the results of truck-truck fatal accidents from 1980-82. UMTRI accident data file was used for the analysis. Overall, a total of 173 fatal accidents involving two medium/heavy trucks occurred in 1980, 138 in 1981 and 127 in 1982. It was not possible to attribute the difference in the numbers of accidents between years to either changes in medium/heavy truck safety or to changes in vehicle usage and mileage.

- Of the 438 accidents, 52.7 percent were between two combination-unit trucks, 22.4 percent between one combination-unit trucks and one single-unit truck and 8.0 percent between two single-unit trucks with no trailers.
- Other univariate tables are presented.

035 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Road Class and Large Truck Involvements in Fatal Accidents," UMTRI, 1986.

Data in UMTRI's new trucks involved in fatal accidents database were analyzed. These data were combined with the FHWA mileage estimates to calculate fatal accident involvement rate for combination trucks. Accidents on rural undivided roads account for 48 percent of the fatal accident involvements of large trucks. Rural non-interstate roads account for 54 percent of the involvements. On a per vehicle mile basis, rural non-interstate roads have the highest fatal accident involvement for large trucks of 0.86 involvements per 10 million VMT; rural interstates have the lowest rate at 0.29 involvements per 10 million VMT. Accident types were found to vary significantly by road class.

In single-vehicle accidents on divided rural roads, crashes into parked vehicles are over-represented at dawn, as are head-on collisions between trucks and another vehicle on undivided rural roads.

036 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Commercial Vehicles Safety: A Report to The Secretary of Transportation by the National Highway Safety Advisory Committee. Report of the Commercial Vehicle Safety Issues subcommittee of the National Highway Safety Advisory Committee.

This report recommends the following approaches in a number of areas critical for heavy truck safety:

- Tailor truck driver training and licensing to the operational requirements of commercial trucks in use.
- Bring the National Driver Register (NDR) onboard as soon as possible.
- Carry out more in-depth accident investigation and collect and analyze truck specific accident data with a view to reducing accidents.
- Encourage States to introduce more effective roadside safety inspection through bodies like the Commercial Vehicle Safety Alliance. Encourage all States to join the alliance.
- Improve driver hours of service and truck driver behavior.
- Educate truck drivers better to the benefits of safety belt use.
- Support the TTBRG.

037 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "Heavy Truck Safety - What We Know," MVMA, 1985.

Fatality rate computed on vehicle miles travelled basis has been dropping continuously from 1925 to date. The fatality rate in 1984 was 2.5 per hundred million VMT. In 1983, 5475 of the 42,584 highway fatalities involved medium/heavy trucks. Eighty-two percent of these fatalities were drivers of "other" vehicles or pedestrians. Seventy-three percent of the fatal multi-vehicle accidents involving combination trucks occurred on two-lane rural roads.

Single-vehicle accidents such as rolling over, or crash with a fixed object represents 30 percent of the fatal accidents but are responsible for 70 percent of the heavy truck occupant fatalities. The author pointed out that there is insufficient data to carry out a definitive safety comparison between the tractor-semis and doubles.

64 percent of combination truck fatalities were driver related, 27 percent were environment related and 9 percent were vehicle related. BMCS in a four State pilot study found that increased truck inspections between 1979-81 resulted in a 25-52 percent reduction in truck accident rates. The author stressed the need for truck drivers to use their safety belts and also pointed out the need for more detailed information on drivers, highway, vehicles, accident forces, handling, braking and stability in panic maneuvers.

038 Motor Vehicle Manufacturers Association (MVMA) supplied copy of: "New Directions in Commercial Vehicle Safety," MVMA 1985.

Gives details of MVMA's efforts to gather meaningful data on heavy truck accidents and their analysis and interpretation. The author described two films on rollover and emergency braking produced by a coalition of industry organizations and government safety agencies. Describes the efforts made by the industry to train safe drivers through the aegis of the Professional Truck Drivers Institute of America. The following suggestions were made:

- Increase random roadside truck inspection through Commercial Vehicle Safety Alliance. Encourage all States to join the Alliance.
- Improve the quality of the truck driver's training, testing and certification. Promote the goals of the Professional Truck Driver Institute of America.
- Enhance the NDR and weed out drivers with bad safety records.
- Adopt a classified truck driver license nationwide.

039 National Highway Traffic Safety Administration (NHTSA)

Results of truck observational/survey studies on the following topics are presented:

- Front Brakes: In California, 505 trucks were examined. 33.5 percent had inoperable front axle brakes by virtue of them being either: not present, having missing or broken parts, or being out-of-adjustment. A fewer percentage of late model year (1976-1986) trucks had inoperable front brakes as compared to earlier (pre 1976) models. Principal reason for inoperable brakes in earlier models was the non-availability of front brake systems. Almost all hydraulic and wedge front brakes were seen to be operable.
- Limiting valves, power steering, and trailer hand valves - In California, 58.6 percent of the inspected vehicles had power steering, 86.5 percent trailer valves and 56.8 percent front axle limiting valves.
- Nine hundred eighty four combination-unit trucks were examined in Maryland. Inoperable brakes were found on 59.4 percent of these. An additional 5.6 percent of the trucks had grease contaminated brakes. Pre 1976 model vehicles had a higher proportion with no front brakes. Limiting valves were found on 45.6 percent, while 61.7 percent had power steering and 94 percent had trolley valves. To some extent, the increase in the incidence of limit valves over time offset the greater incidence of working front brakes on newer vehicles.
- Prevalence of Aeroaids and Clipped Bumpers: 1850 trucks were observed in California. Tractor/van had greatest percentage of aeroaids (39 percent) and clipped bumpers (6.6 percent). Three point two percent of all vehicles had damaged fuel tanks.
- Truck Behavior on Down Grades: In a study in California, on two grades (4.5 percent and 5.9 percent grades), about the same percentage of drivers, 47 percent and 41 percent respectively, did not use brakes. On the steeper grade, a larger percentage (35 percent) of trucks applied brakes continuously as opposed to 14 percent who applied brakes continuously on the gentler grade.

- A larger percentage (39 percent) of trucks applied brakes intermittently on the less steep grade than on the steeper grade.
- Truck Behavior on Highway Interchanges: In California, 978 trucks and 904 cars were observed traversing interchanges/curves. Average speed of cars at any location was higher than that of the trucks at the same location. At some intersections, the traffic flow governed the vehicle speed while at others it was the roadway geometry. No trailer wheel "lift-off" was observed during this study.

- Truck Lighting Survey: in California, 1154 trucks were surveyed. 759 (65.8 percent) were vans, 280 (24.3 percent) were flatbeds and 115 (10.0 percent) were tankers. One or more lights were found to be out on 14.6 percent of the vehicles. Of the vans, 88 percent had ID lights at the high location. Also, 39.5 percent of the vans had high mounted clearance lights. More than 90 percent of the vans, flatbeds, and tankers had more than the required number of lights. In general, over 50 percent of the vehicles had minimum number of side marker lights. Of a subset of 119 trucks observed, none had reflective material.

- Many lighting configurations that just met FMVSS 108 had less intense lights and/or dirty lenses. With a few exceptions, trucks with more than the minimum required array of lights never had fewer functional lights than required.

040 The Centerline Steering Safety Axle Corporation

Reports their inability to provide test data, as planned, relative to their product's performance.

041 Insurance Institute for Highway Safety (IIHS)

Provided an excerpt from an IIHS Status Report which reported the result of a survey of 1084 adults, the majority of whom were said to be in favor of national licensing for truck drivers.

042 Insurance Institute for Highway Safety (IIHS)

Suggests that technology and justification are both available to immediately:

- Complete rulemaking on already proposed rear underride guard regulations.
- Begin rulemaking for front underride protection.
- Prohibit removal of brakes on front axles.
- Require automatic brake adjustment.
- Improve brake compatibility between tractors and trailers.
- Require faster brake timing.
- Require load sensing as a minimum with antilock the preferable option.
- Reinstate the FMVSS121 stopping distance requirements.
- Establish a mechanism to ensure appropriate minimum truck driver licensing standards in all states.
- Require on-board computers and/or tachographs to monitor driver performance.

*U. S. GOVERNMENT PRINTING OFFICE 1987: 181-783/64632